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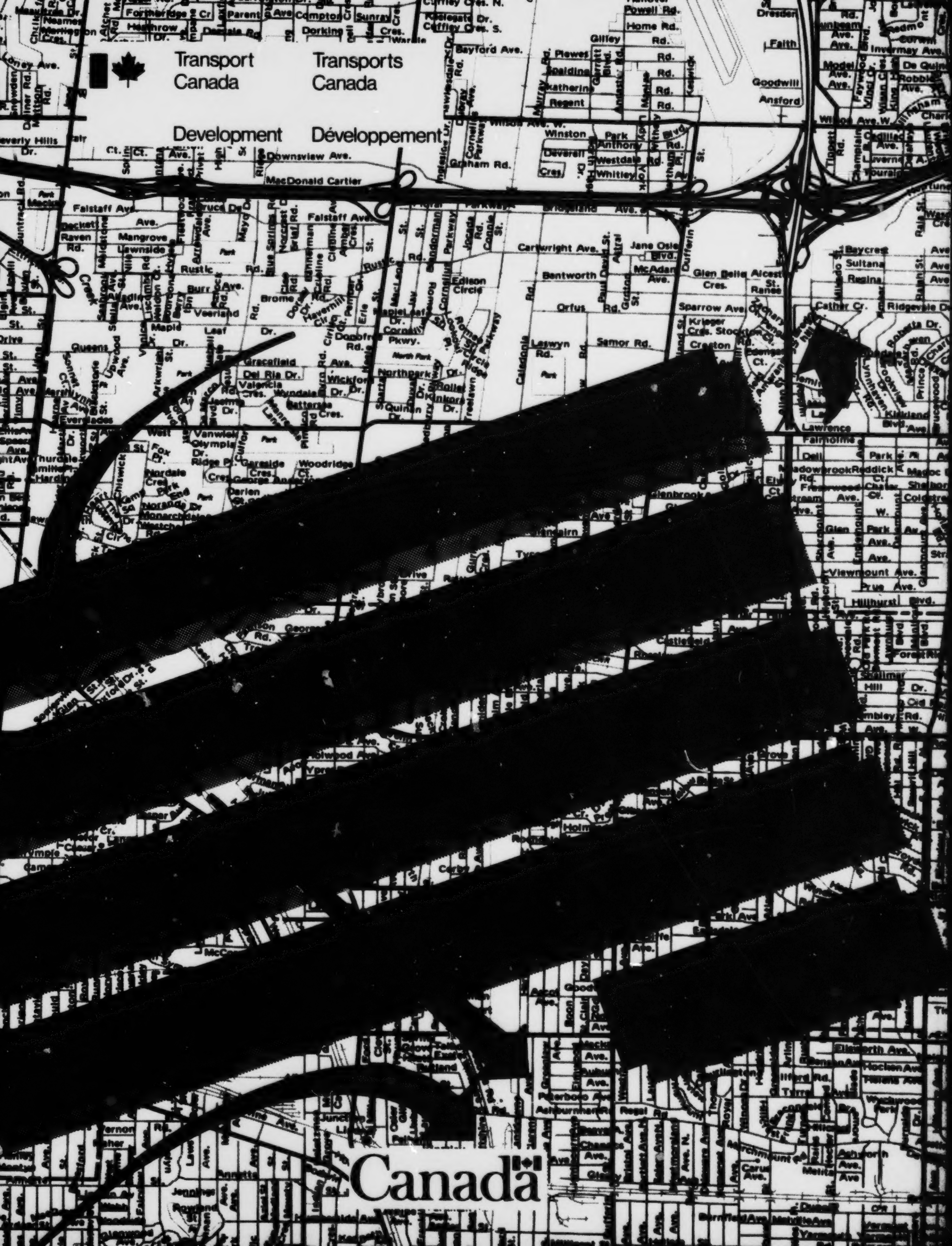

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Transportation Development Centre
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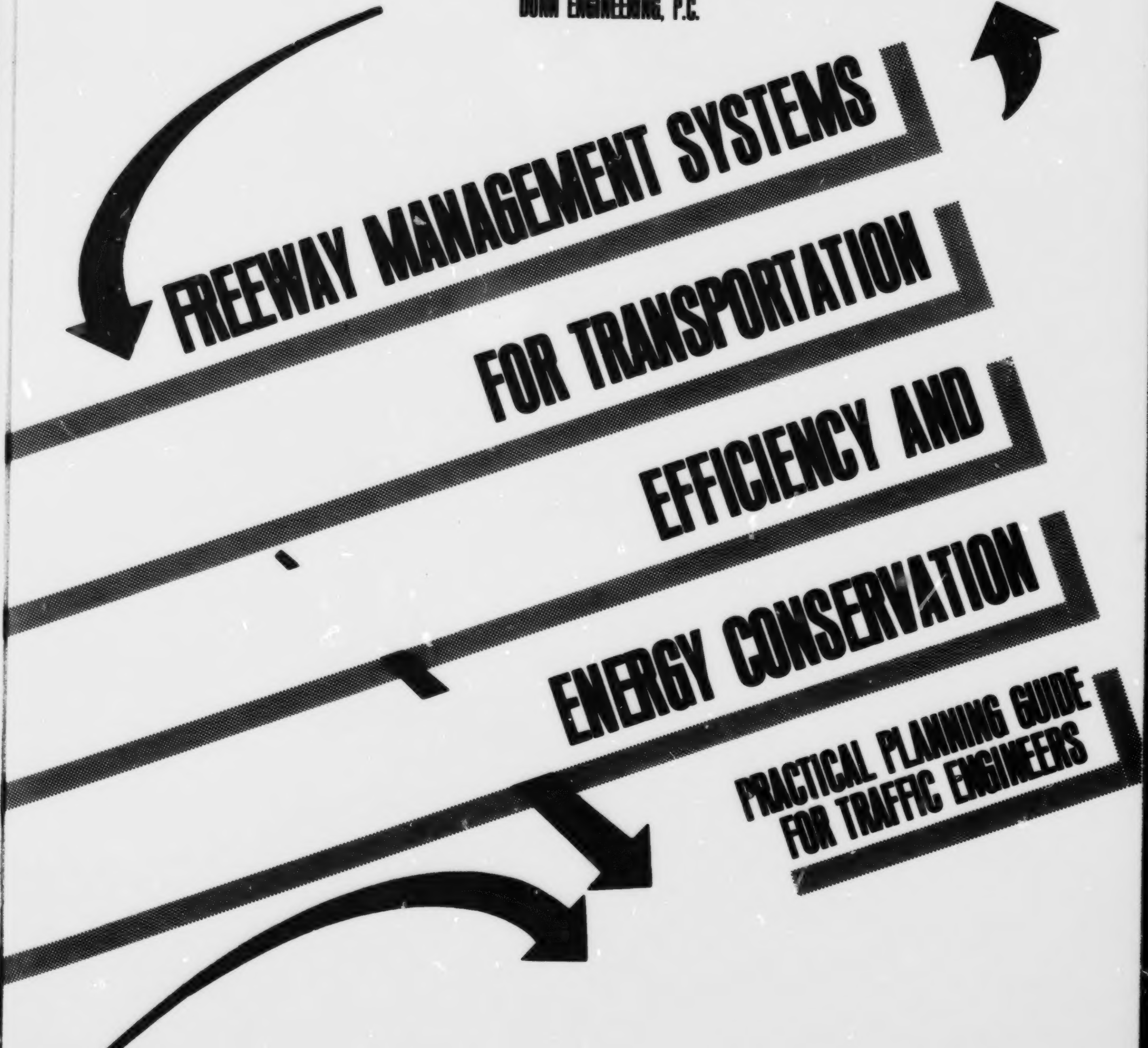
prepared by
Jouko A. Parviainen
JOUKO A. PARVIAINEN & ASSOCIATES
Walter M. Dunn, Jr.
DUNN ENGINEERING, P.C.



FREEWAY MANAGEMENT SYSTEMS FOR TRANSPORTATION EFFICIENCY AND ENERGY CONSERVATION

PRACTICAL PLANNING GUIDE FOR TRAFFIC ENGINEERS

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PROJECT TEAM

Jouko A. Parviainen, P.Eng.
JOUKO A. PARVIAINEN & ASSOCIATES

Walter M. Dunn, Jr. P.E.
Joy Walker
DUNN ENGINEERING, P.C.

Douglas G. Miller
SYNERGISTICS CONSULTING LIMITED

Eugene A. Smaller
Lynda A.V. Wilson
BELBIN + MINERS TYPOGRAPHY LIMITED

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Jouko A. Parviainen (Jouko A. Parviainen & Associates)
Walter M. Dunn, Jr. (Dunn Engineering, P.C.)

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9. Performing Organization Name and Address
Jouko A. Parviainen & Associates
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Oakville, Ontario
L6J 2L3

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16. TDC Project Officer
Catherine Hirou

17. Abstract

This planning guide has been developed for transportation planners and traffic engineers, at the working and research levels, who are responsible for initiating, designing and implementing freeway management systems.

The guide includes summaries of a wide range of freeway management techniques:

- *incident management: detection/verification/response*
- *driver information: changeable message signs/highway advisory radio/in-vehicle guidance/trip planning*
- *alternative routing*
- *preferential treatment of high-occupancy vehicles*
- *centralized computer control and communications systems.*

For each technique, the guide includes — in addition to a general description:

- *specific systems available: their advantages and disadvantages*
- *equipment used*
- *cost components and rough cost estimates*
- *application criteria.*

The planning guide also includes a recommended evaluation process by which users can select freeway management techniques best suited to local travel demand and road management circumstances. The evaluation process includes specific measures of effectiveness to rate the performance of each technique in relation to the goals and objectives of improved traffic flow and conservation of financial and natural resources. Planning and coordination requirements for successful implementation are also outlined.

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16. Agent de projet — CDT
Catherine Hirou

17. Résumé

Le présent guide a été rédigé à l'intention des planificateurs et des ingénieurs responsables de la planification, de la conception et de l'implantation des systèmes de gestion des autoroutes. Il traite de diverses techniques de gestion, notamment :

- *la détection et la vérification d'incidents routiers et l'intervention d'urgence;*
- *l'information des usagers : signaux à indications variables, communications par radio ou par un équipement spécial à bord des véhicules, préparation d'itinéraires;*
- *le détournement des usagers;*
- *les voies réservées aux véhicules à taux d'occupation élevé;*
- *les systèmes centralisés de communication et de commande assistées par ordinateur;*

En plus d'une description générale de chaque technique de gestion, le guide fournit :

- *les divers systèmes applicables, ainsi que les avantages et les inconvénients inhérents à chacun;*
- *les équipements nécessaires à leur mise en oeuvre;*
- *une ventilation et une estimation approximative des coûts;*
- *des critères d'applicabilité.*

Ce guide de planification contient également une méthode d'évaluation des diverses techniques de gestion des autoroutes pour aider à choisir la solution la mieux adaptée aux conditions particulières d'exploitation. Cette méthode permet de mesurer l'efficacité de chaque technique en termes d'écoulement du trafic, de rentabilité et d'économie des ressources naturelles. Enfin, ce guide souligne les éléments de planification et de coordination indispensables à la réussite de l'opération.

18. Mots-clés
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S. Ling Suen (Chairperson)	Transportation Development Centre, TC
Catherine Hirou	Transportation Development Centre, TC
Ian F. Gilbert	Energy R&D, Transport Canada
Peter Reilly-Roe	Energy, Mines and Resources Canada
Jan H. Van Der Veen	Energy, Mines and Resources Canada
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John B.L. Robinson	Roads and Transportation Association of Canada
Pierre La Fontaine	Ministry of Transportation — Province of Quebec
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Jean-Claude Larrivée	Ministry of Transportation — Province of Quebec
Marcel Mercier	Ministry of Transportation — Province of Quebec
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Milton D. Harmelink	Ministry of Transportation and Communications — Province of Ontario
E. Ryerson Case	Ministry of Transportation and Communications — Province of Ontario
Leon Root	Alberta Transportation
Stephen H. Reynolds	Ministry of Transportation and Highways Province of British Columbia

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1.
INTRODUCTION

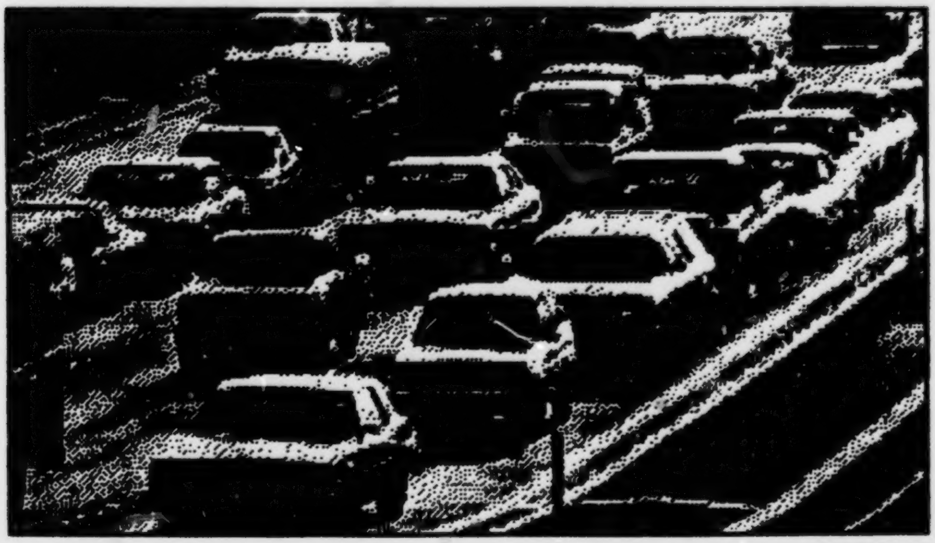


Exhibit 1a

1.1
Transportation /Energy Problem

Since the 1973-74 oil embargo, and the 1979 fuel shortage in the U.S., energy has emerged as a critical factor in public policy and decision making in Canada. There now is a general awareness of the need to conserve energy — particularly in the transportation sector, which consumes half of all petroleum products. These energy problems have coincided with a worsening economic situation that requires more careful allocation of all financial and natural resources — including energy.

Much of the consumption of petroleum products by the transportation sector occurs within urban areas, particularly in the main travel corridors and within the congested downtown street networks. This high energy consumption coincides with the heavy congestion that occurs during the traffic peak periods and during the occurrence of incidents. During these situations, wasteful stop-and-go conditions are imposed on both passenger and freight vehicles.

Freeway management systems have been successful in reducing delays, minimizing stop-and-go conditions, reducing the gasoline consumed, and reducing the emission of vehicular pollutants. These systems are considered highly cost effective in comparison to the more conventional methods of providing new capacity on freeways, such as the widening of existing facilities and the construction of new facilities. In energy conservation terms, freeway management systems also offer a very significant bonus compared to new construction, as they can save the indirect energy that would have been used for the construction itself as well as the energy that would have been required to maintain the additional facilities. Most importantly, freeway management systems — which really involve managing, fine tuning and optimizing the operation of the existing road system — do not encourage the proliferation of travel, which almost always occurs when new facilities are provided in major metropolitan areas.

In addition to the above energy related and financial benefits, freeway management systems make a significant contribution to the reduction of automotive pollutants.

1.2 Federal Government Program

As part of the National Energy Program (NEP), the Federal Government of Canada has established the "Conservation in Transportation" Program. One of the major objectives of the program is to assess the state-of-the-art in traffic operations techniques, and then transmit the findings to the agencies in charge, the practising engineers and planners, and the decision makers, through demonstration projects and other technology transfer techniques.

In recognition of the importance of energy conservation in the transportation sector, and in accordance with the specific objectives of the Conservation in Transportation Program, the Transportation Development Centre (TDC) of Transport Canada has approved and sponsored a project entitled, "Freeway Management Systems for Transportation Efficiency and Energy Conservation". A proposal for this project was received in response to a Department of Supply and Services Request for Proposals announced on behalf of the Energy R&D Program of Transport Canada in January 1983.

The ultimate goal of the "Freeway Management Systems for Transportation Efficiency and Energy Conservation" project is to increase the efficiency of passenger and freight transportation in major Canadian urban corridors. The project is aimed at collecting information on current freeway management system concepts and documenting these in a format that will encourage the review and implementation of these systems in Canada.

1.3 Description of Planning Guide

Project Reports

This report, entitled "Practical Planning Guide for Traffic Engineers", is one of four reports prepared during Phase I of the "Freeway Management Systems for Transportation Efficiency and Energy Conservation" project. The four reports are:

- "Summary of North American and European Projects" — which presents a state-of-the-art summary of selected major freeway management projects already implemented or under construction in North America and Europe.
- "Bibliography of Key References" — which contains a highly selected bibliography of technical literature considered to be most useful as a reference to practising traffic engineers who require more comprehensive information and examination of approaches used in several selected projects.
- "Practical Planning Guide for Traffic Engineers" — which can be used as an introductory planning guide by traffic engineers and transportation planners at the working and research levels who are responsible for planning, designing and implementing freeway management systems.
- "Overview" — which describes the various freeway management concepts and their main applications at a more strategic level — making it a potentially useful reference for the senior management and other decision-makers.

Planning Guide Objectives

"Practical Planning Guide for Traffic Engineers" has been developed for use by practising traffic engineers, at the working and research levels, who will be responsible for initiating, designing and implementing freeway management systems. This document is also for the use of transportation planners wishing to increase their familiarity with freeway management systems.

This document has not been prepared to serve as a cookbook or a complete design manual for freeway management systems. Furthermore, the purpose is not to provide all the technical knowledge required to construct and operate such systems — but rather, to provide enough information for an engineer to be able to make some of the preliminary decisions for planning, designing and implementing the various techniques that comprise a typical freeway management system.

This document has been designed to provide the practising traffic engineer with sufficient background information that will permit the understanding of concepts and the appreciation of alternative techniques. The sections have been tailored to provide information on the techniques, their individual advantages and disadvantages, their costs, and the situations under which one technique is preferred over an alternative technique. With the help of this material, the traffic engineers will hopefully be able to perform preliminary trade-off assessments for their site specific circumstances.

Report Structure

The report has been divided into the following sections:

- Introduction
  (Chapter 1)
- Rationale for Freeway Management
  (Chapter 2)
- Summary of Available Strategies
  (Chapter 3)
- Freeway Management Tehniques
  (Chapters 4 thru 16)
- Implementation Steps
  (Chapter 17)
- Evaluation of Freeway Management System
  (Chapter 18)

Chapter 2, Rationale for Freeway Management, describes reasons for initiating freeway management systems in major urban areas. These are primarily implemented in the place of (or in conjunction with) construction of additional lanes of freeways — which, by themselves, never obviate the need to address and manage the day-to-day problems of recurring and non-recurring types of congestion. A review of basic goals of freeway management systems is presented in the light of specific objectives to achieve these goals.

Chapter 3, Summary of Available Strategies, categorizes various types of freeway management systems. Low cost alternative systems that can be readily implemented are defined. Types of overall packages that can be implemented in a short time frame and on a small scale are presented in the light of achieving the greatest overall impact for the entire system. The significance of selecting an integrated system where all elements act together and complement each other is stressed.

Chapters 4 through 16 present information on the main freeway management components that may be implemented by themselves or in conjunction with each other to comprise a freeway management system. These chapters have been organized to present:

1. a conceptual outline for each component:
2. a description of alternative techniques within each component — with an examination of the advantages and disadvantages of each;
3. the primary equipment and devices of the available techniques;
4. the cost elements of the techniques; approximate order-of-magnitude costs are also presented, but only as a rough guide [at each site, specific estimates will have to be made]; and
5. specific application criteria under which one particular alternative system, component or technique may be preferable.

Chapter 17, Implementation Steps, describes the primary steps necessary for successful selection, construction, operation and maintenance of a freeway management system.

Chapter 18, Evaluation of Freeway Management System, describes various measures of effectiveness that can be utilized to evaluate the extent of success in the implementation and operation of a freeway management system. The measures of effectiveness stress the need to conduct before and after studies and to continually monitor and evaluate the operation of such systems. A step-by-step evaluation of the various alternative techniques, described in this chapter, would typically include the use of:

a) advantages/disadvantages exhibits;
b) application criteria charts;
c) performance ratings;
d) linear scoring functions; and
e) standard benefit/cost techniques.

2.

RATIONALE FOR FREEWAY MANAGEMENT

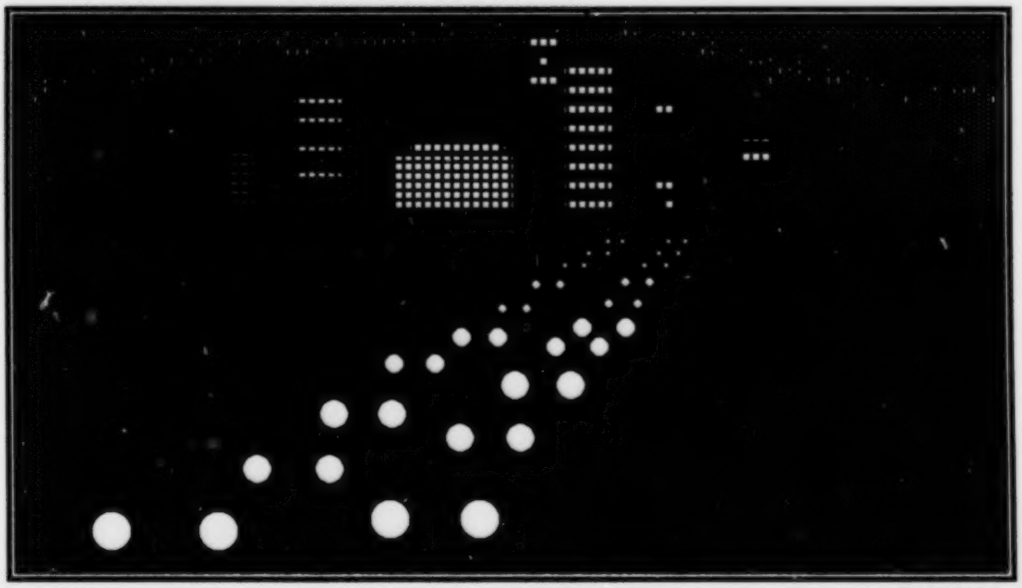


Exhibit 2a

2.1

Local Needs for Freeway Improvements

During the last decade, planners, public and politicians have become increasingly aware of the transportation related energy problems which are highly visible in the main travel corridors and the central business districts of major urban areas. The need for improvements in the existing freeway systems are continually being discussed and examined by the responsible planning agencies — from the standpoints of four major interrelated problem areas:

1. traffic: reduced congestion, increased accessibility (ie. reduced, or at least predictable travel times), and improvements in comfort and safety;
2. energy: reduced consumption of direct and indirect energy;
3. environment: reduction in air pollutant emissions and in raw material requirements; and
4. available monies: deference and avoidance of expenditures, and obtaining the most benefits with the least expenditures.

In recent years — when the transportation sector has been in increasingly fierce competition with other sectors (eg. housing, welfare, fire & police,...) for the same tax dollars — the fourth problem area has risen to a particular preeminence.

The specific objectives, that may be considered by the metropolitan planning agencies, by which to further define the above goals, are presented in Exhibit 2b.

Exhibit 2b

OVERALL GOALS AND OBJECTIVES OF FREEWAY MANAGEMENT SYSTEMS

GOALS	OBJECTIVES
Traffic Management	
• Reduced Congestion	a. Coordinated implementation of traffic operations measures
	b. Reduction in peak vehicle demands — optimum use of total corridor capacities — spreading of traffic peaks — shift from SOVs to HOVs
	c. Quicker detection, verification and clearance of incidents
• Increased Accessibility	d. Increased person throughput
	e. More predictable vehicle throughput
• Improved Comfort and Safety	f. Smoother traffic flow with adequate vehicle spacings
	g. Improved routing and driver information
	h. Improved incident response
Conservation of Energy	i. Reduced use of (direct) energy by: — vehicles on the freeway — all vehicles on adjacent and 'receiving' facilities (eg. CBD network and freeway access streets)
	j. Reduced consumption of (indirect) energy required for construction and maintenance of additional facilities (including energy impeded in asphalt)
Conservation of Environment	k. Reduced emission of air pollutants by reducing: — stop-and-go traffic conditions — number of single occupant vehicles
	l. Reduced raw material (eg. aggregates) requirements and consumption
Conservation of Money	m. Deferred and avoided construction and maintenance of additional major road facilities by optimizing use of all existing: — parallel road facilities — transit infrastructure and service
	n. Improved allocation of moneys amongst competing short and medium term transportation system management (TSM) improvements based on: — use of proper cost-benefit techniques — recognition of system wide implications.

2.2 National Recognition of Needs

In the United States, specific national legislative efforts have been undertaken within the past decade to ensure that these goals are recognized in a significant and consistent way at both the state and municipal levels:

- Issuance, in 1975, of the Transportation System Management (TSM) regulations — which stressed the need for a balanced transportation system that can be achieved through the use of specific TSM measures (eg. preferential treatments for high occupancy vehicles (HOVs), improvements in traffic signal operations, parking management, freeway surveillance and control systems, etc.).
- Enactment, by the Environmental Protection Agency (EPA), of regulations — which stressed the need to implement 'reasonably available (transportation) control measures' (RACMs) to improve the air quality and the environment. These regulations were followed with specific "Action Plans" by the states, to ensure consistent applications by the MPOs.
- The creation, in 1975, of conservation programs by the Federal Energy Administration (FEA) — which required all states to develop State Energy Conservation Plans (SECPs) that included the specific preparation of a conservation plan for the transportation sector.

These legislative efforts strongly complement each other by emphasizing essentially the same set of transportation efficiency measures that have been identified by the local metropolitan transportation agencies.

A similar development occurred at the national level in Canada, when the Federal Government established the Conservation in Transportation Sub-Program within the National Energy Program — which recognized the need to achieve energy conservation through the implementation of, among other things, various traffic control measures.

In some provinces and municipalities, the requirement for the conservation of all resources — energy, environment and money — has been recognized through significant changes in the evaluation processes and subsidy criteria related to the provision of transportation infrastructure and service. These changes have emerged basically in the past 10 years, somewhat following the U.S. programs (albeit usually without similar legislative support) — and have, more recently, included the establishment of specific transportation energy management programs (such as 'TEMP' in Ontario — a joint program of the Ministry of Transportation and Communications and the Ministry of Energy).

In both countries, it has been most significant that the transportation control and management measures, which have been found to support the main goals and objectives, are so similar and closely resemble each other. This has, in some cases, resulted in some new, innovative measures being given serious consideration for the first time — when, in the past, they were viewed as too innovative or simply too 'tough'. In particular, the opportunity exists to strive towards these goals through the use of many proven TSM techniques available in the area of freeway traffic and travel demand management.

2.3 Specific Rationale for Freeway Management

Although the need for implementing transportation system management measures has been recognized by both metropolitan and local municipal transportation planning agencies, and by national legislative or other actions, many agencies have attempted to alleviate their transportation and traffic problems solely by the construction of additional lanes and new road facilities. Once the additional lanes or facilities have been constructed, these urban transportation agencies have been bewildered to observe the occurrence of exactly the same traffic problems that they felt would be alleviated by the new construction. In these situations, a different approach is called for.

Once a particular traffic problem has been identified by the traffic engineer, alternative approaches for obviating the problem should be determined. The main alternatives that are often evaluated, are presented in Exhibit 2c.

If freeway management type techniques have not been previously implemented within a particular metropolitan area, it is very likely that the local planners and engineers will have to provide an extensive examination of, and justification for, the use of those techniques. In many cases, freeway management techniques may be considered too innovative, or "pie in the sky" futuristic solutions. On the other hand — in many major metropolitan areas such as Los Angeles, where additional capacity has been previously sought solely through the addition of a travel lane by:

a) the physical construction of a travel lane, or
b) restriping the entire roadway with narrower travel lanes, or
c) using the roadway shoulder as a travel lane during peak hours,

the need for freeway management systems has been recognized quite readily. In such heavily urbanized locations, the occurrence of an incident usually has a drastic effect on the operation of the freeway. As an example — the percentage reduction in the capacity for Gulf Freeway in Houston, Texas (which has three lanes in each direction) is presented in Exhibit 2d.

Exhibit 2c

ALTERNATIVE APPROACHES

- Do Nothing: regular maintenance & periodic rehabilitation
- Low Cost TSM: single, low cost measures
- TSM: freeway management system
- Major Plant Rehabilitation
- Plant Expansion: addition of an extra travel lane
- Construction of a New Freeway Facility

Exhibit 2d

CAPACITY REDUCTION RESULTING FROM LANE BLOCKAGE

Number of Lanes Blocked	Capacity Reduction (Percent)
Shoulder only	33%
One Lane	50%
Two Lanes	79%

Of particular interest is the substantial reduction in capacity due to the presence on the shoulder of the freeway of vehicles that have stalled or have been involved in an accident. The need to manage the daily operation of the freeways (even after lanes have been added or new facilities constructed) — in order to increase/retain their operating efficiency — has been recognized in most major metropolitan areas.

To draw a parallel — the construction of an office building or an industrial facility includes the commitment, beyond the physical structure itself, to address the day-to-day needs of the businesses occupying the structure. In large buildings, specific management and operation responsibilities are assigned to assure the comfort, convenience and safety of the human beings within the building. These conveniences include adequate heating, ventilation, air conditioning and other necessary services to meet the needs of the people using the facility.

The same daily management and operation functions are necessary for freeway facilities. A commitment must be made to manage and operate the freeways in urban travel corridors and around major cities. This will require the implementation of freeway management systems that can consist of:

a) an individual technique — implemented to resolve an isolated traffic problem; or
b) a package of several techniques — eg. HOV lanes and by-pass ramps, preferential downtown parking, and urban fringe parking — implemented to obtain maximum benefits through the synergistic effect of the individual measures.

Additional reasons that may be used to justify the expenditure of money for freeway management systems are discussed in Chapter 3 in the section entitled "Complementary Packages". Marketing plans, which have included the publication of special 'management brochures', have been used successfully in several agencies to illustrate to the senior transportation officials and politicians the need and benefits of freeway management systems. Sophisticated computer simulations have also been done to assure the decision makers that the anticipated benefits of the proposed techniques are significant and that they can be achieved.

Exhibit 2e is a pictorial of a five lane section of a freeway in Los Angeles, California. With the provision of five highway lanes in one direction, a substantial increase in the capacity of the roadway section was achieved; however, the occurrence of an accident -- such as the over-turned school bus that blocks the freeway — emphasizes the fact that no matter how many lanes are provided, there is a need to manage the day-to-day operation of the freeway facility.

Specific alternative techniques that can be utilized to reduce the impact of such an accident through the use of freeway management are presented in Chapters 4 through 16 of this planning guide. Many of these techniques are based on:

a) monitoring the freeways to determine what is actually occurring in terms of traffic flow conditions;

b) exercising proper control to alleviate and avoid the impacts of high traffic volumes and incidents;

c) employing traffic management measures to maintain the freeway at an optimal level to reduce stop-and-go conditions;

d) detecting and responding to incidents with appropriate emergency services — in order to minimize delays to other drivers; and

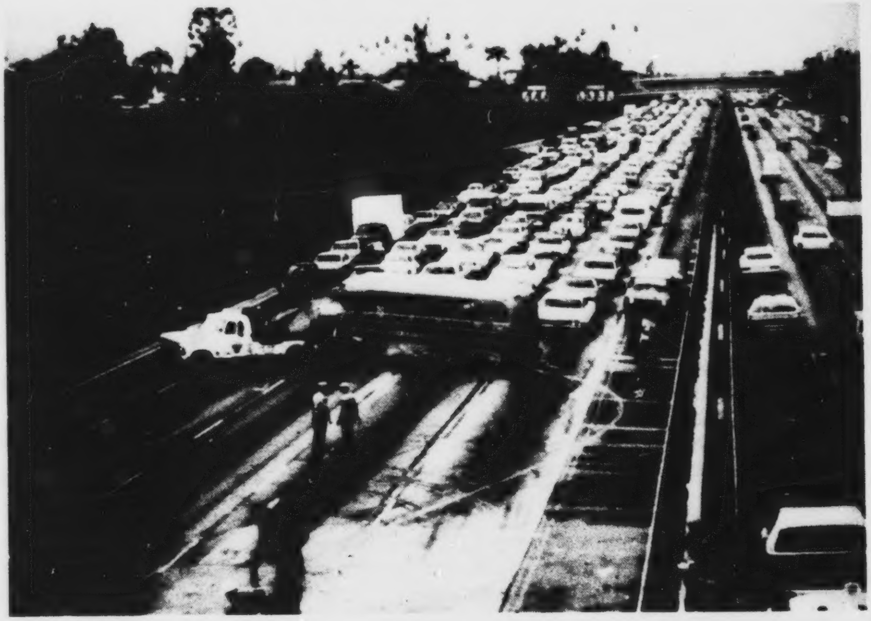
e) providing information on freeway conditions to drivers.

Although past emphasis has been placed on the extension and completion of freeways throughout the provinces and across the country, it has been recognized that the construction of a freeway is not an end result in itself. Once the facility is constructed, operations and maintenance needs must be fully addressed and those responsibilities assumed by appropriate agencies. In the past, many highway agencies have viewed their operational and maintenance responsibilities as simply relating to the physical plant. They have addressed these needs via grass mowing operations, patching and repair of pavement, pavement resurfacing, bridge rehabilitation, and snow plowing operations. However, these activities, in most cases, address only part of the needs of the drivers who incure the so familiar daily congestion during their trips to and from work. In addition, maintenance and construction operations (albeit necessary and best done during off-peak hours) can add havoc to trips purposely timed for off-peak by motorists and trucking companies trying to avoid peak congestion.

Exhibit 2e

IMPACT OF AN INCIDENT ON A MAJOR FREEWAY

— Los Angeles, California —



2.4 Energy Conservation Relationship of Goals and Objectives

Freeway management systems have been initiated on the basis of achieving a variety of traffic engineering goals. In many cases these goals have been sequenced in order of priority, with the first choice varying depending upon whether the list was prepared from the viewpoint of the responsible government agency — or of the daily commuter, who is exposed to both:

- recurrent congestion — congestion that occurs daily due to geometric limitations or a capacity limitation; and
- non-recurrent congestion — congestion that occurs as a result of an incident, maintenance operation, or a special event.

A listing of the primary goals and objectives of freeway management systems, together with the associated energy conservation relationship, is presented in Exhibit 2f. An examination of each of the individual traffic engineering goals and objectives reveals that each has a corresponding energy conservation benefit. For instance, the accomplishment of increased travel speeds and more even traffic flow reduces the need for excessive deceleration and acceleration, which in turn reduces fuel consumption.

Exhibit 2g, Fuel Consumption at Uniform Speeds, indicates the fuel consumed in litres per 1000 vehicle kilometres for various steady speeds maintained by drivers of light duty vehicles. This exhibit reveals that a steady speed of approximately 50-55 km/h yields the best fuel efficiency — ie. a speed which is significantly greater than the typical peak hour average speeds (on heavily congested sections of urban freeways).

By reducing stop-and-go conditions and wide fluctuations in speeds on highways, significant reductions in the consumption of fuel can be achieved. The approximate additional litres of fuel consumed for every 1000 speed changes by an average vehicle — compared to vehicles maintaining steady speeds — are presented in Exhibit 2h: Additional Fuel Consumption Due to Speed Changes.

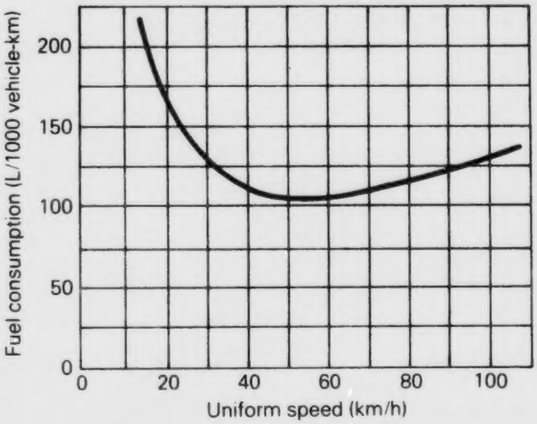
Exhibit 2f

SPECIFIC GOALS AND OBJECTIVES OF FREEWAY MANAGEMENT SYSTEMS

GOALS	OBJECTIVES	ENERGY CONSERVATION RELATIONSHIP
1. Improved vehicle thoughput	• Increase corridor throughput during peak periods • Accommodate new demand with existing facilities	• Increased throughput yields improved speeds which reduce fuel consumption (and CO and HC emissions)
2. Decreased and more predictable travel time	• Decrease average travel times • Reduce variability of average travel times • Reduce number of incidents	• More even traffic flow - ie. less deceleration and acceleration - reduces fuel consumption
3. Rapid detection and removal of capacity reducing incidents	• Reduce incident detection time • Reduce incident response time • Reduce incident clearance time	• Reduced clearance time reduces total number of vehicles caught in severe stop-and-go and idling thereby reducing fuel consumption
4. Timely assistance to stranded motorists	• Reduce time between breakdown/stop and contact with authorities • Decrease response time to provide assistance	• Same as 3. above
5. Reduction in accidents	• Reduce number of accidents • Reduce number of secondary accidents • Reduce severity of accidents	• Reduction in accident induced stop-and-go cycles reduces fuel consumption • Reduced number of accidents and vehicle damage reduces energy used in vehicle repair and manufacturing and roadside rehabilitation
6. Reduction in air pollution	• Reduce undesirable vehicle emissions	• Emissions reduction is directly related to fuel consumption
7. Reduction in energy consumption	• Reduce use of direct and indirect energy	• Prime objective
8. Reduction in vehicle operating costs	• Reduce fuel and maintenance costs	• Some increase in fuel consumption due to increased driving
9. Improved trip information	• Increase number of motorists given advisory information • Reduce number of lost motorists • Reduce accidents due to motorists confusion about direction or path • Increase accuracy and timeliness of advisory information	• Reduction in circuity of driving reduces fuel consumption • Advance avoidance of congested sites reduces fuel consumption in total (even though for a single vehicle, increased circuity may increase consumption)
10. Improved comfort of motorists	• Increase the ease of handling vehicle in traffic flow	• N/A
11. Improved management of existing highway facilities	• Increase effectiveness of road system (eg. utilization of all parallel facilities) • Defer/avert the cost of constructing and maintaining new facilities	• Defer/avert energy use for construction and maintenance of new facilities • Avoid additional fuel consumption caused by the proliferation of vehicle travel (always the result of major capacity additions in metropolitan areas)
12. Reduction of total number of vehicles in peak traffic flow	• Encourge solo drivers to shift into car, van and bus pools and to use regular public transit	• Reduction in number of vehicles commuting long distances significantly reduces total fuel consumption • Subsequent reduction in construction and maintenance requirements of new facilities (as per 11.)
13. Increased knowledge and experience with freeway managament	• Provide transferable results for use in planning and designing new projects throughout Canada	• Overall nationwide energy conservation

Exhibit 2g

FUEL CONSUMPTION AT UNIFORM SPEEDS
—Light-duty Vehicles—

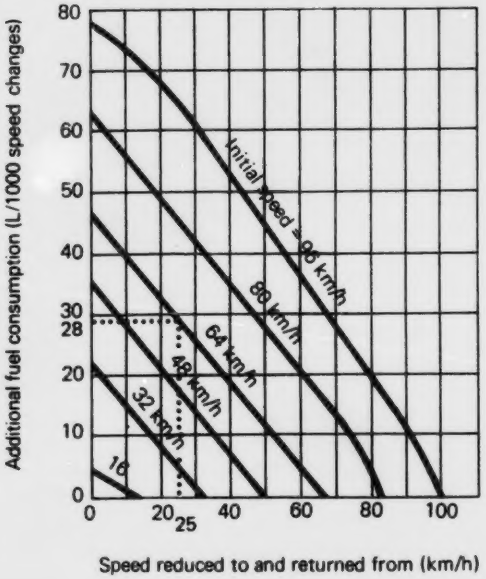


Traffic moving at uniform speeds minimizes fuel consumption, accidents, noise and air pollution.

The most fuel-efficient uniform speed is about 53 km/h.

Exhibit 2h

ADDITIONAL FUEL CONSUMPTION DUE TO SPEED CHANGES
—Light-duty Vehicles—



For example, a traffic impediment requiring vehicles to change speed from 64 km/h to 25 km/h then back to 64 km/h will result in an additional 28.1 litres of fuel being consumed for every 1000 speed changes (compared to those vehicles continuing at uniform speed).

3.
SUMMARY OF AVAILABLE STRATEGIES

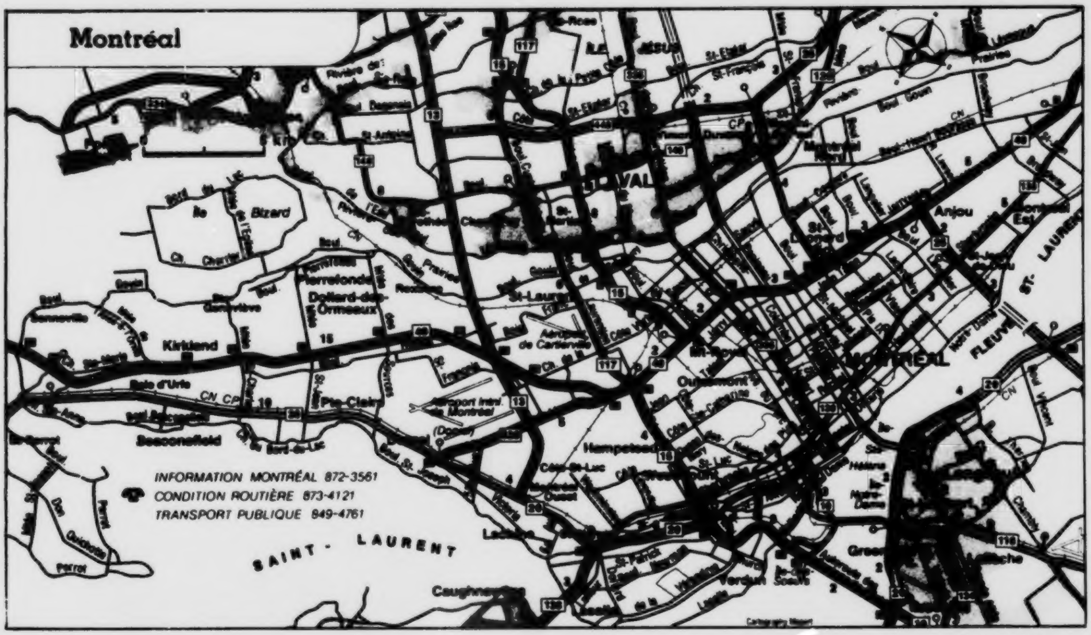

Montréal
Laval
Anjou
Kirkland
Beaconsfield
Baie d'Urfé
Pte-Claire
Dollard-des-Ormeaux
Pierrefonds
Île Bizard
Aéroport de Cartierville
Aéroport Intl. de Montréal (Dorval)
Hampstead
Côte-St-Luc
Outremont
Montréal
Verdun
Caughnawaga
Saint - Laurent
Fleuve St. Laurent
INFORMATION MONTRÉAL 872-3561
CONDITION ROUTIÈRE 873-4121
TRANSPORT PUBLIQUE 849-4761

Exhibit 3a

3.1
Introduction

In order for the practising engineer to be able to select a freeway management system for a particular project location, the goals and objectives of the project must be transformed into specific management approaches and system components. To accomplish this, the traffic engineer must be aware of numerous issues that will influence the selection and decision making process. It will be particularly important to recognize the full range of site specific constraints and opportunities peculiar to that locality's transportation planning circumstances—in order to assure that the best practical design is selected. Some of these typical site specific realities are contained in Exhibit 3b.

3.2
Classification of Projects

There are two major methods of classifying freeway management and control systems:

- by management techniques; and
- by hierarchical categories of roadways.

In the first method, the various types of detection, verification, response, control and communications elements are identified—and the freeway management system is classified accordingly. This approach was adopted as a basis for structuring this 'Practical Planning Guide for Traffic Engineers': the classifications have become the titles for Chapters 4 through 16 (as indicated in Exhibit 3c). Most freeway management and control systems, of course, contain a multiple of these elements — and are therefore classified as multiple-type systems.

In the second method of classifying freeway management and control systems, the roadways included and their configuration are used as the determining factors. The primary classifications, their descriptions and example configurations for typical management systems are presented in Exhibit 3d.

Exhibit 3b

SITE SPECIFIC CONSTRAINTS AND OPPORTUNITIES

ISSUE	EXAMPLES
• Geographic Layout	• Rivers (Bridges) • Mountains (Tunnels)
• Environmental Effects	• Ice and snow complicating, on some days each year, replacement of HOV lane indicator cones • Severe fogging on a highway section requiring advance driver warning • Rock slides on long mountain road stretches requiring advance driver information
• Jurisdictional Responsibilities	• Coordination of municipal, provincial and federal interests • Adjacent developments restricting construction of a continuous exclusive high occupancy vehicle (HOV) through-lane
• System Wide Constraints	• Parallel facilities not capable, without major traffic operations improvements, of absorbing diverted traffic • Addition of CBD parking, to handle continued growth in single occupant vehicle (SOV) traffic, not possible • Adjacent developments restricting construction of a continuous exclusive high occupancy vehicle (HOV) through lane
• Planning Realities	• Unfamiliarity, by many planners and engineers, with innovative and perhaps all freeway management techniques • Lack of confidence, that strong TSM measures (eg. exclusive HOV ramps in CBD) can be "sold" to decision makers • The common misconception that traffic can grow (as per 'models') beyond the practical throughput capacity of a corridor
• Political Realities	• Opinion that ramp metering penalizes localities closest to the city (and favours proliferation of wasteful long distance commuting) • The 'invisible' freeway management measures still not as popular as grand schemes of road and transit improvements • Pressure to turn on operation before system is fully tested • Lack of determination to carry through in the face of vocal opposition (nearness of elections)
• Public Realities	• Drivers of SOVs not in agreement with the economic and social rationale that 4 taxpayers in one vehicle (=carpool) deserve preferential treatment compared to 1 taxpayer in one vehicle • Strong support from environmental and neighbourhood groups for freeway management systems which help prevent construction of more major roadways.

Exhibit 3c

TYPES OF FREEWAY MANAGEMENT SYSTEMS
—Classification by Management Technique—

Chapter	Classification Title
4	Incident Detection Systems
5	Incident Verification Systems
6	Incident Response Systems (including Motorist Aid Systems)
7	Bridge/Tunnel Surveillance and Control
8	Ramp Metering Systems
9	HOV Preferential Facilities
10	Driver Information Signing
11	Highway Advisory Radio
12	In-Vehicle Guidance
13	Pre-Trip Planning
14	Arterial Signals
15	Communications Interface
16	Centralized Computer Control Facilities

Exhibit 3d

TYPES OF FREEWAY MANAGEMENT SYSTEMS
—Classification by Hierarchical Categories of Roadways—

CLASSIFICATION	DESCRIPTION	POSSIBLE SYSTEM CONFIGURATIONS
• Spot Location Management	• System is implemented at a specific location on a freeway facility	• Entry or exit ramp • Point facility (bridge or tunnel) • Geometric constraint location • Environmentally sensitive location
• Linear Facility Management	• System is implemented on a single freeway facility (usually limited to the main line and major ramps)	• Single, limited access facility — freeway — urban expressway — parkway
• Mini-Corridor Management	• System includes the freeway mainline, its ramps, and freeway service and frontage roads	• Freeway and service roads • Parkway and a parallel arterial
• Corridor Management	• System includes: — the freeway mainline, its ramps, service and frontage roads — parallel freeway or other limited access facility — network of transverse roadways	• Freeway and service roads and parallel major arterials • Two parallel freeways and their service roads • Two parallel freeways and their service roads & adjacent parallel and perpendicular arterials
• Area-Wide Management	• System encompasses all freeways within a metropolitan area	• All freeways in a metropolitan area • All freeways and major arterials • All freeways and the major street network

3.3 Concept of Corridor and Area Systems

Corridor and area wide freeway management systems incorporate basic freeway management and control techniques with the technique of route diversion. The traffic on all the roadways included in such a system is guided so that each vehicle may take full advantage of alternative, noncircuitous driving paths from where it is located (when an incident occurs) towards its final destination. The Freeway Management Team has the ability to detect capacity restrictions caused by an incident on any of the monitored roadways of the corridor or the area—and to reroute traffic to alternative roadways, which have been identified to have spare capacity at the time of the incident. The rerouting is achieved via driver information techniques, such as variable message signs or highway advisory radio.

The alternative routes can be either:

- other freeways within the corridor or the area; or
- parallel arterial roadways.

In the latter case, the traffic flow on the arterials must be also monitored in realtime—requiring the installation of surveillance detectors. In addition, a traffic signal system may be installed on service roads that may be adjacent to the freeway facility. The signal control for the arterials, and the service roads, must be responsive and brought under some form of central computer control to be operated in conjunction with the freeway management system.

The primary reason for introducing the computerized signal system is to maximize the available throughput capacity of the arterial roadway during times when traffic is diverted from the freeway core lanes and the service roads. In practise, the throughput is maximized by giving preference to vehicles travelling in the direction of the freeway—usually at the (temporary) expense of the flows on the crossing arterials (ie. lasting until the incident is cleared and the freeway brought back to normal operation).

If the arterial signal system has not been previously computerized (perhaps it is even without any interconnection), the imnplementation of a freeway corridor management system—which includes the arterial roadway—will provide significant benefits during all time periods.

The technique of ramp metering can also be used by the Freeway Management Team to cause traffic to divert to a flanking service road system. This is accomplished by controlling the rate—at which motorists are allowed to enter the freeway from an entrance ramp—with a traffic signal, that permits only one (or two) vehicle(s) at the time to enter the freeway. The rate at which the ramp meter is operated is based on the capacity of the freeway to handle the merging traffic—and may be selected by the management team from the control centre. A motorists approaching the queue at the ramp may elect to utilize the service road, or even his/her own improvized path, rather than wait at the ramp meter. This will help balance the flows on the entire corridor system to better match the available capacities.

3.4 Concept of Integrated Systems

A freeway management approach, which has been adopted for several large projects in the United States, calls for the integrated implementation of numerous individual components. By installing all the components at one time, the total system costs can be substantially reduced. An example of such a project is the Integrated Motorist Information System (or IMIS) on Long Island, New York. The basic approach within IMIS has been to demonstrate the effectiveness of state-of-the-art equipment and realtime responsive control techniques in the management of traffic in a major, existing highway corridor. By combining the individual techniques into an integrated design, it has been possible to provide a more cost-effective system capable of addressing a greater portion of the traffic-related problems. In the IMIS project, surveillance and control functions are combined with a comprehensive system of driver information and driver services.

3.5 Concept of Complementary Packages

A typical freeway traffic management and control system incorporates a number of elements (as per Exhibit 3c) for which specific surveillance, administrative, organizational and pre-planning options must be selected. As an example, typical low cost alternatives available in the incident management area (Chapters 4-6) are presented in Exhibit 3e.

The true challenge, however, in attempting to design a cost-effective system is always in the identification of individual techniques and management approaches that will best complement each other. Rather than selecting several unrelated techniques that will provide some individual benefits, it is usually preferable to implement a complementary package of several techniques—whereby the overall impact can be far greater than the (theoretical) total from the individual components.

Two examples of complementary packages that can be compiled —for incident management and for HOV preferential treatment strategies—are presented in Exhibit 3f.

In developing freeway management strategies for the preferential treatment of high occupancy vehicles, this packaging of complementary incentive/disincentive measures is particularly critical. Maximum benefits can be only obtained by the implementation of a carefully staged program which contains both incentives to HOVs and disincentives to SOVs. By including measures in a "string", or through the entire length of a corridor, the individual measures can be less penalizing to SOVs (at each specific location) while the HOVs will still gain a substantial total door-to-door travel time benefit—by accumulating the savings at each location (eg. entry ramp, lane, exit ramp, CBD parking).

3.6 Summary of Available Strategies

An overall summary of the main freeway management strategies is presented in Exhibit 3g. The various approaches that can be utilized under each strategy are noted. The individual techniques (with a numbered reference to the corresponding Chapters 4-16), that are particularly applicable to each specific approach, are indicated with a tick mark. The overall strategy should be developed, and the individual measures selected, in accordance with the goals and objectives of the freeway management system.

Exhibit 3e

FREEWAY INCIDENT MANAGEMENT SYSTEMS
—Low Cost Alternatives—

POLICE AGENCY	TRANSPORTATION AGENCY	POINT FACILITY	CITIZEN GROUP	INCIDENT MANAGEMENT TEAM
		Surveillance Options		
Increased Police Patrol Peak Period Mtrcycle Patrol CB Radio Monitoring Police Service Patrol Stationary Response Vehicle Aircraft	CB Radio Monitoring Call Boxes Service Patrol Stationary Response Vehicle	Professional Observers Stationary Response Vehicle Increased Police Patrol Call Boxes Closed Circuit TV Loop Detectors Peak Period Mtrcycle Patrol	CB Radio Monitoring Volunteer Observers Mobile Service Patrol	Increased Patrol Frequency CB Radio Monitoring Call Boxes Peak Period Mtrcycle Patrol Service Patrol Stationary Response Vehicle Aircraft
		Administrative Options		
Emergency Lights Policy Dedicated Freeway Patrol Fast Vehicle Removal	Emergency Lights Policy Fast Vehicle Removal Accident Investigation Sites	Fast Vehicle Removal Accident Investigation Sites Dedicated Freeway Patrol	Fast Vehicle Removal	Emergency Lights Policy Dedicated Freeway Patrol Fast Vehicle Removal Accident Investigation Sites
		Organizational Options		
Highway Agency Relationship Wrecker Contracts Other Public Agency Rlships Citizen Group Liaison Media Ties Prv Sector Service Coord'n Fwy Telephone Trouble No	Police Relationship Prv Sector Service Coord'n Media Ties Other Public Agency Rlships Wrecker Contracts Citizen Group Liaison Ties with Transit Fwy Telephone Trouble No	Wrecker Contracts Media Ties Other Public Agency Rlships Prv Sector Service Coord'n Citizen Group Liaison	Police/Ministry Rlships Media Ties Prv Sector Service Coord	Other Public Agency Rlships Response Team Wrecker Contracts Media Ties Prv Sector Service Coord'n Citizen Group Liaison Ties with Transit Fwy Telephone Trouble No
		Pre-planning Options		
Traffic Operations Training Dispatcher's Manual Hazardous Materials Manual	Traffic Operations Training Alternative Route Planning Dispatcher's Manual Communications Training	Hazardous Materials Manual Traffic Control Plan Dispatcher's Manual Traffic Operations Training	Communications Training Information Digest	Alternative Route Planning Traffic Operations Training Dispatcher's Manual Hazardous Materials Manual Communications Training

Exhibit 3f

COMPLEMENTARY PACKAGES

—Two Examples—

STRATEGY	COMPLEMENTARY PACKAGE	
• Incident Management	• On-site incident management team	
	• Loop detection	
	• Verification	— remote CB radio monitors — CCTV
	• Motorist aid	— call boxes
	• Response	— courtesy patrols — tow trucks — medical emergency teams
	• Clearance	— tow trucks
	• Control	— variable message signs — highway advisory radio — alternative routing
	• News dissemination	— radio, TV, papers — pre-trip planning
• HOV Preferential Treatments	• Metropolitan fringe park-and-ride lots near major interchanges	
	• Priority entry onto freeway mainline through HOV by-pass lanes and ramps	
	• Concurrent or contraflow lane on freeway reserved for buses, vanpools and carpools	
	• Exclusive freeway exit ramps for HOVs to enter downtown	
	• CBD parking: municipal lots/garages nearest to major employment concentrations designated exclusively to HOVs from 6 a.m. to 11 a.m. (Monday to Friday)	

Exhibit 3g
SUMMARY OF FREEWAY MANAGEMENT STRATEGIES

STRATEGY	APPROACH	APPLICABLE TECHNIQUES																										
		INCIDENT MANAGEMENT													CONTROL FEATURES													
		DETECTION						VERIFICATION			RESPONSE				BRIDGE/TUNNEL SURVEILLANCE & CONTROL						RAMP METERING			HOV PREFERENTIAL FACILITIES				
		[4]						[5]			[6]				[7]						[8]			[9]				
		Electronic Surveillance	Patrol Vehicles	Aerial Surveillance	CB Radio	Emergency Phone	Call Box	CCTV	Remote CB Radio Monitoring	Police Patrol	Courtesy Patrol	Police Car	Tow Trucks	Heavy Duty Equipment	CCTV	Closely Spaced Loop Detection	Increased Police	Emergency Response	Traffic Control Signals & Variable Message Signs	24 h Operations	Fixed Time	Traffic Responsive	System Responsive	Exclusive Facility	Use of Existing Lane	Preferential Ramp	Preferential Parking	Signal Pre-emption
1. Improve Vehicle Throughput	• Smooth traffic flow • Improve incident management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓					
2. Increase Person Throughput	• Reduce SOV usage																							✓	✓	✓	✓	✓
	• Increase HOV (buses, vanpools, carpools) usage																							✓	✓	✓	✓	✓
3. Improve Travel Time	• Divert traffic to alternative roadways	✓																										
4. Enchance Detection and Removal of Capacity Reducing Incidents	• Establish incident management techniques										✓	✓	✓	✓	✓	✓	✓	✓										
	• Reduce incident detection time	✓	✓	✓	✓																							
	• Reduce incident response time							✓	✓	✓	✓	✓	✓	✓	✓			✓										
	• Reduce incident clearance time							✓	✓	✓	✓	✓	✓	✓	✓			✓										
5. Improve Safety and Security of Motorists	• Provide motorist aid					✓	✓																					
	• Reduce accidents	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓														
	• Reduce secondary accidents	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓														
6. Improve Communications with Motorist	• Provide information dissemination																											
	• Provide information signing																		✓									
7. Improve Bottleneck Conditions at Point Facilities	• Provide intensified implementation														✓	✓	✓	✓	✓	✓								
8. Optimize Route Advisory Information	• Provide alternative routing information	✓																										
	• Increase timeliness & accuracy of information	✓																										
9. Improve Traffic Conditions During Incidents	• Provide information to avoid site • Divert to alternative • Use local roadway or alternative prior to entering freeway	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓									
10. Improve Management and Efficiency of System	• Increase field equipment • Increase staff	✓						✓	✓		✓		✓	✓	✓	✓					✓	✓	✓					

Key: [ ] indicates chapter where detailed information is provided

(continued on next page)

Exhibit 3g
SUMMARY OF FREEWAY MANAGEMENT STRATEGIES (continued)

STRATEGY	APPROACH	APPLICABLE TECHNIQUES																										
		CONTROL FEATURES																										
		DRIVER INFORMATION SIGNING							HIGHWAY ADV. RADIO		IN VEHICLE GUIDANCE			PRE TRIP PLANNING			ARTERIAL SIGNALS		COMMUNICATIONS					CENTRAL COMPUTER CONTROL				
			Variable Message Signs [10]						[11]		[12]			[13]			[14]		[15]					[16]				
		Diversion Alternative Routing	Roller Shade	Rotating Drum	Lamp Matrix	Disk Matrix	Flap Matrix	Fibre-Optic	Cable Radiator Antenna	Monopole Antenna	In-Vehicle Display	Vehicle Detectors	Communications	Telephone Call-In Number	Teletype Communications	Cable TV Station	Hierarchical	Centralized	Twisted Wire Pairs	Coaxial Cable	Fibre Optics Cable	Radio Transmission	Computer	Computer Peripherals	Control Console	Central Communications Unit	Map Display	System Monitors
1. Improve Vehicle Throughput	• Smooth traffic flow • Improve incident management	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2. Increase Person Throughput	• Reduce SOV usage • Increase HOV (bus, vanpool, carpool) usage																											
3. Improve Travel Time	• Divert traffic to alternative roadways	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓												
4. Enchance Detection and Removal of Capacity Reducing Incidents	• Establish incident management techniques • Reduce incident detection time • Reduce incident response time • Reduce incident clearance time																											
5. Improve Safety and Security of Motorists	• Provide motorist aid • Reduce accidents • Reduce secondary accidents																											
6. Improve Communications with Motorist	• Provide information dissemination	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							✓					
	• Provide information signing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										✓					
7. Improve Bottleneck Conditions at Point Facilities	• Provide intensified implementation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓															
8. Optimize Route Advisory Information	• Provide alternative routing information	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓															
	• Increase timeliness & accuracy of information	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓												
9. Improve Traffic Conditions During Incidents	• Provide information to avoid site	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓												
	• Divert to alternative	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓												
	• Use local roadway or alternative prior to entering freeway	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓												
10. Improve Management and Efficiency of System	• Increase field equipment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓						
	• Increase staff															✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Key: [ ] indicates chapter where detailed information is provided

4.
INCIDENT DETECTION

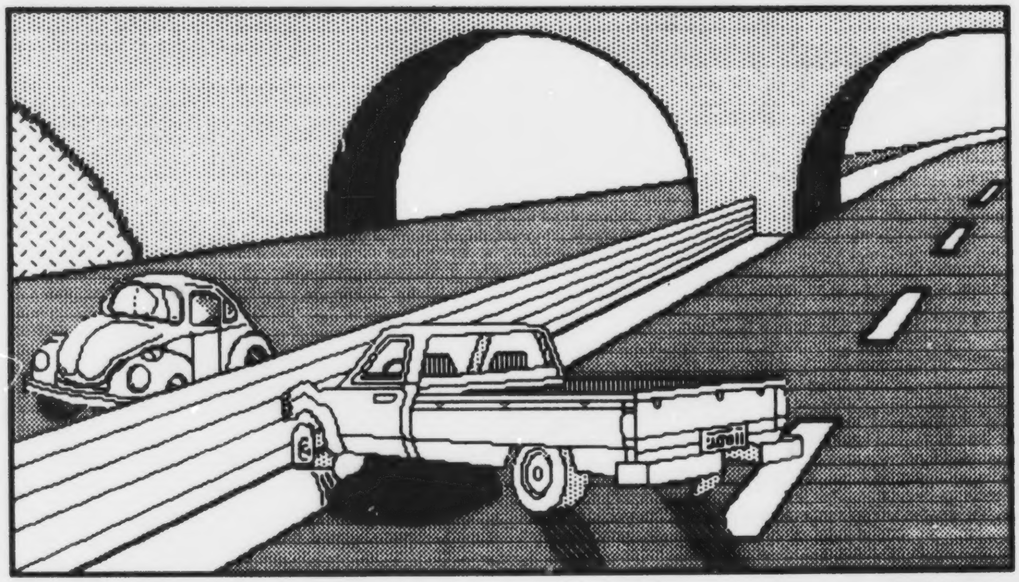


Exhibit 4a

4.1 Concept

Oftentimes, a motorist is caught in a traffic jam that is caused by an incident on a freeway or expressway. The incident could be either:

a) an accident,
b) a vehicle breakdown,
c) a lane closure due to maintenance or construction activity; or
d) "rubbernecking" by motorists looking at an accident or construction activity on the other side of the roadway.

In addition to wondering how long he/she will be stuck behind the incident blockage, the motorist is often frustrated by not knowing whether the incident has been detected or reported to the operating agency in charge of the highway facility.

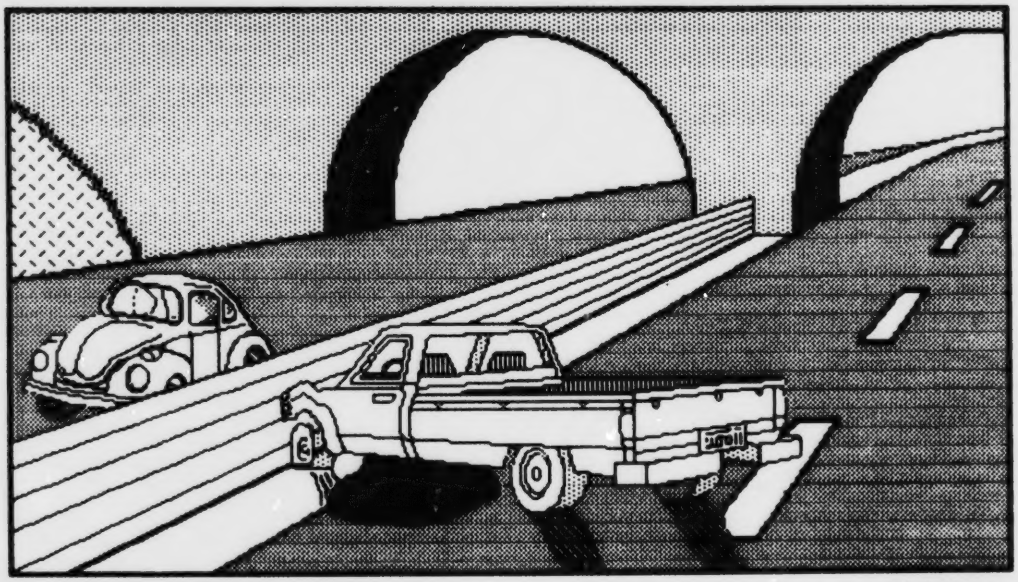
The purpose of an incident detection system is to detect an incident as soon as it occurs so that it can be quickly removed from the thru travel lanes of the roadway. Thus, delays to motorists trapped behind the incident can be minimized and the roadway returned to its "normal" operating condition.

Although motorist aid systems were initially used in some locations as part of an incident detection system, in recent projects they have been primarily utilized to obtain assistance for motorists whose vehicles have broken down alongside main highway facilities. When the inopportune occasion occurs where a motorist's vehicle breaks down along a freeway or expressway due to some mechanical or other problem (e.g. overheating of the radiator, the vehicle running out of gasoline), the motorist will usually require assistance. Even though numerous vehicles may pass by on the highway, the motorist must decide to either wait in the vehicle until noticed by a passing police patrol — or walk along the highway to the closest interchange to obtain help. From traffic safety and flow standpoints, the two major concerns are for:

1) the safety of the motorist;
2) the removal of the vehicle from the highway facility so that the traffic flow is not slowed or otherwise affected by the phenomenon of "rubbernecking".

Since several past studies have indicated that the average life expectancy of a pedestrian walking along a freeway or expressway is approximately 20 minutes, consideration should be given to the installation of a readily accessible motorist aid system — in order that the location and needs of the motorist can be determined and a proper emergency response taken.

4.
INCIDENT DETECTION



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Since several past studies have indicated that the average life expectancy of a pedestrian walking along a freeway or expressway is approximately 20 minutes, consideration should be given to the installation of a readily accessible motorist aid system — in order that the location and needs of the motorist can be determined and a proper emergency response taken.

4.2 Techniques

Electronic Surveillance

Electronic surveillance is the primary technique used in incident detection systems for major freeway management projects. Generally, inductance loop detectors are selected:

- since they do not exhibit inaccurate readings due to fading of operation; and
- since such detectors are either "on" or "off", it is easy to tell if they are working properly.

In most systems, loop detectors are embedded in each lane of the roadway at roughly 800m intervals (Exhibit 4b). 'Occupancy' is the major traffic parameter that is obtained from the detectors. Occupancy is defined as the percentage of time that a vehicle occupies the space directly over a loop detector. By comparing occupancy readings, i.e. differences at one station and at an adjacent upstream or downstream station, an indication of the traffic operation and/or traffic congestion on a roadway can be determined.

Through the use of an electronic surveillance system, a major accident (such as an accident between two tractor trailer trucks that blocks an entire roadway) can be detected almost immediately. The surveillance system would note the presence of high occupancy readings at the upstream detector station due to vehicles trapped behind the accident — while the downstream detector, past the accident location, would indicate no readings since vehicles could not get past the accident blockage. Thus, such a major accident would be detected immediately by the electronic surveillance system.

The primary advantages of using electronic surveillance for an incident detection system are:

- entire sections of roadways can be monitored continuously from a single central location; and
- operating costs are low when compared with most other techniques.

However, the installation of an inductance loop incident detection system can be quite costly and time consuming — which must be recognized when planning and designing freeway management systems.

Patrol Vehicles

Police in patrol vehicles, or staff in an agency's maintenance or courtesy patrol vehicles (which have 2-way radios) — who normally travel on highway facilities during their daily work assignments — may see an incident occuring and can then quickly report the exact type of the incident to their headquarters. This will allow the initiation of a proper response to that specific incident (Exhibit 4c).

However, patrol vehicles are usually not used in freeway management systems as the primary method of detecting incidents since their use is quite costly in terms of manpower requirements, the initial purchase of the vehicles, and their continued operation and upkeep. Furthermore, the detection times are usually considered too variable since they so heavily depend on the actual routes and dis-

Exhibit 4b
INDUCTANCE LOOP DETECTORS

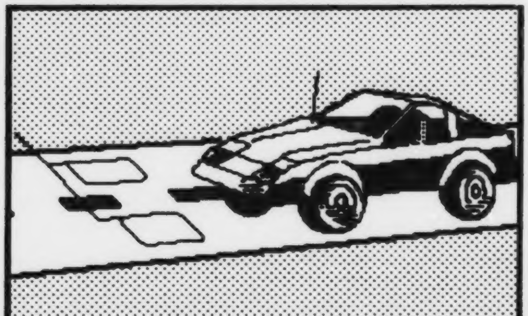
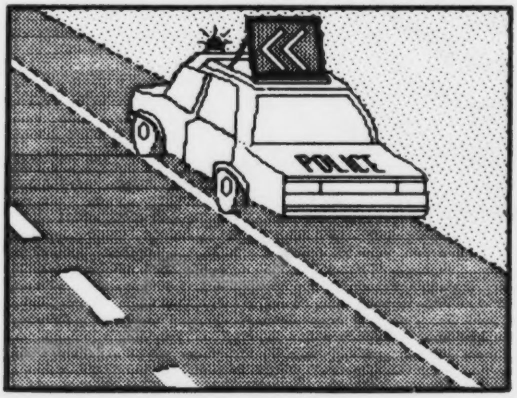


Exhibit 4c
POLICE PATROL VEHICLE



tances over which the patrols travel. The patrol vehicles, in practice, can only serve as an additional, but most useful means of detecting incidents and verifying their exact nature. In many, less complicated incidents, they can also provide emergency aid once they have arrived on site.

Helicopters & Small Airplanes

Helicopters and small airplanes may be used for aerial surveillance of traffic conditions on metropolitan freeway and arterial networks (Exhibit 4d). When an incident is detected through aerial surveillance, an instant verification of the type of the incident is usually provided — even though some specifics may not be known (e.g. whether an engine problem or an empty gasoline tank). Limitations to the use occur during times of adverse weather, when flights may not be permitted or visibility may be poor.

The use of helicopters or small airplanes by government agencies for the (exclusive) purpose of detecting traffic incidents has been considered prohibitively expensive due to the high initial investment costs for purchase, and the high labour and operating costs. In some locations, helicopters and small planes — which are utilized in routine police patrols — may undertake incident detection as a secondary function during their scheduled flights. However, in the most common application, local radio stations (often several competing ones) own the helicopters or planes and provide traffic reports as public service announcements. Additional, more complete reports may also be transmitted (during regular programming) to the police and the highway operating agencies.

Citizens Band Radio

Motorists whose vehicles are equipped with a citizens band radio, and who happen to detect an incident, may report it over the C.B. radio (Exhibit 4e). In freeway corridors, where there are clearly designated emergency channels — which, the public knows, are being continually monitored — the experiences have been quite favourable. However, there are limitations to the sole reliance on C.B. radios for detecting incidents — namely, the timeliness of the information and the problem of multiple reporting even after incidents may have been cleared from the roadway. Also, continual monitoring of C.B. channels solely for incident detection purposes can be quite tedious on the staff. It is also necessary to establish the monitoring system near/within each highway corridor in order to transmit the information back to a central control centre for action.

Motorist Aid Emergency Telephones

Emergency telephones have been located at intervals along freeways and expressways so that a motorist, whose vehicle is disabled, can notify the operating agency of the breakdown and get assistance. When the motorist reaches the emergency telephone box and picks up the telephone (Exhibit 4f), he/she is automatically connected to an operator who notes the location and the type of the breakdown, and sends out the appropriate emergency response vehicle. It should be noted that an emergency telephone system requires voice transmission. Thus, the information is conveyed orally by direct conversation between the motorist and the system operator so that the specific needs and specific responses are fully identified.

Exhibit 4d
AERIAL SURVEILLANCE

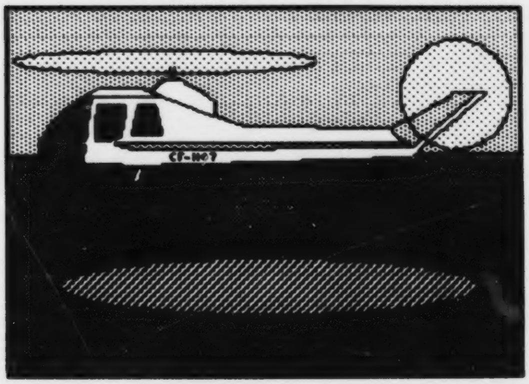
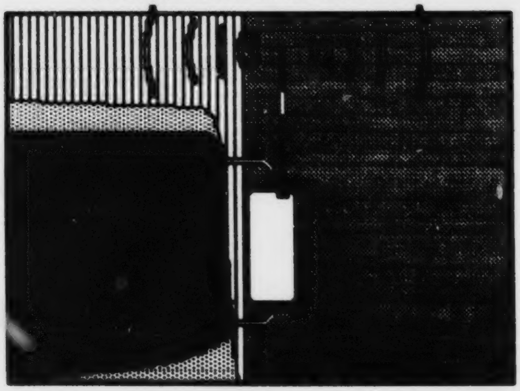


Exhibit 4e
CITIZENS BAND RADIO



Motorist Aid Call Boxes

Motorist aid call boxes are also located at intervals alongside a freeway or expressway so that a motorist can seek assistance from the operating agency. Once the call box is opened, the motorist can seek aid by pushing appropriate buttons (Exhibit 4g). When the first button is pushed, the specific call box location is immediately identified in the motorist aid command facility. Specific buttons can then be selected to indicate the need for an ambulance, a police vehicle, a tow truck, etc. On certain types of call boxes, even the specific nature of a breakdown can also be identified.

One specific advantage of the call box system occurs at bilingual project locations, where pictorial symbols can be used to label the buttons that should be pushed to request the necessary emergency response service (example, picture of a police car or an ambulance). This can sometimes avoid what would have otherwise been verbal communication problems.

Although a system of call boxes with coded message buttons is usually less expensive than an emergency telephone system which requires voice transmission, the latter system may be preferable in most circumstances. Studies have indicated that certain types of problems occur more often with a call box operation, since direct oral dialogue is not established between the motorist and the system operator. These problems include:

a) confirming that proper action has been requested;

b) determining if multiple vehicle breakdowns have occurred in the event that several calls are placed at the same call box — perhaps by an impatient motorist who has not yet received aid; and

c) the emergency response vehicles arriving at the site and finding that the motorist is no longer in the area — perhaps because the motorist has repaired the breakdown or overcome some other problem for which the aid call was placed.

4.3 Equipment

As stated above, the most reliable and responsive incident detection system utilizes electronic surveillance techniques to monitor roadway conditions. Such a surveillance system is comprised of the following elements:

- loop detectors embedded in the roadway pavement
- loop detector amplifier (one amplifier may monitor up to 4 loops on individual channels)
- field cabinet to house amplifiers and communications equipment
- communications system, which may do some preprocessing of detector data in the remote communications unit. (see Chapter 15: Communications Interface)
- central processing facility, where a computer software program (algorithm) processes either voice or preprocessed field data and determines the roadway operating characteristics (see Chapter 16: Centralized Computer Control Facilities).

The roadway loop is constructed by placing a wire in a slot that is saw cut a minimum of 4 cm (1½ inches) into the pavement surface. The slot forms a rectangle (or diamond) with a lead-in slot running to a conduit at the edge of the roadway. Loop wire is coiled several times around the rectangle (usually 2m x 2m)

Exhibit 4f
EMERGENCY TELEPHONE

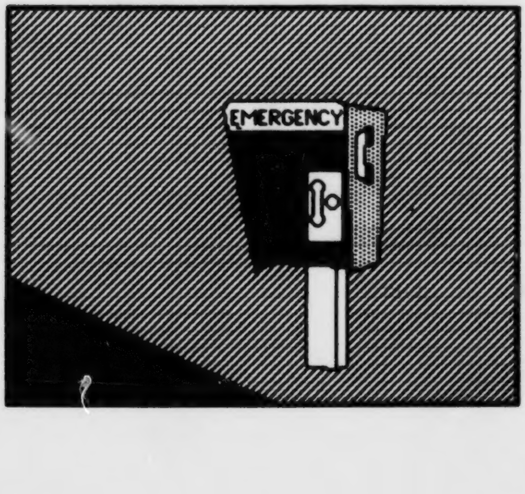
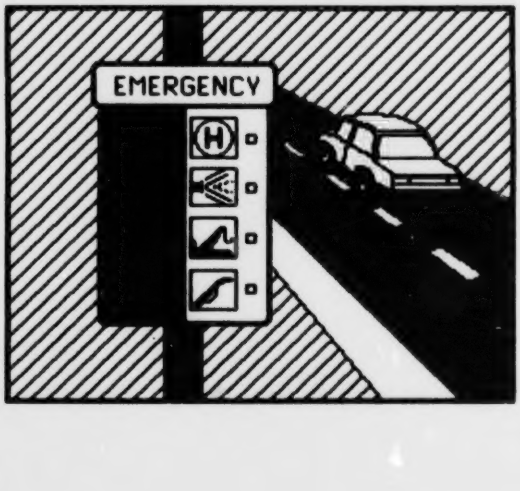


Exhibit 4g
MOTORIST AID CALL BOX



and the slot is sealed with either epoxy or hot asphalt. The amplifier senses the base inductance of the loop and responds to changes in the inductance created by vehicles moving through the field of influence of the loop.

Emergency telephones provide the stranded motorist with direct communications to the operator who can summon the required assistance. The field telephone must be connected by either:

a) regular leased telephone lines;
b) an agency owned communications cable system; or
c) a radio transmitter and receiver at each field location.

A motorist call box, while simpler than the emergency phone, also requires a communications system to relay information from the field to a central location.

4.4 Cost Components

Representative costs for the installation of detection and motorist aid systems are presented in the following:

- **Electronic Surveillance System**
  (without communications and cabinets)

• Inductance Loop Wire	30m/loop	@	$ 3.25/m	= $100
• Sawcut & Seal	9m/loop	@	$ 15/m	= $135
• Pull box	1	@	$500	= $500
• Conduit	3m	@	$ 20/m	= $ 60
• Detector Amplifier	1	@	$250	= $250

A typical sensor station would consist of one loop per lane on the freeway. For a three lane freeway, a typical sensor station with one pullbox and three amplifiers would cost approximately $1 545. In addition, the field station would require a communications unit and field cabinet.

- **Emergency Phone or Call box**
  (without communications)

• Emergency Phone or Call Box ...	$ 1 600/location
• Central Monitoring Equipment ..	$20 000/system
• Central Control	$40 000/system

The above costs, as the costs contained in the following chapters (5-16), are order-of-magnitude costs only presented as an approximate guideline for the practicing engineer. At each site, specific estimates will have to be made to fully consider the local traffic operations, available infrastructure and contracting circumstances.

4.5 Application Criteria

In comparing the applicability of alternative incident detection systems to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 4h.

Exhibit 4h
APPLICATION CRITERIA FOR INCIDENT DETECTION TECHNIQUES

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS					
					Motorist Aid	
	Electronic Surveillance	Patrol Vehicles	Aerial Surveillance	CB Radio	Emergency Telephone	Call Box
• Senses incidents automatically	✓	—	—	—	—	—
• Depends on regular patrols	—	✓	✓	—	—	—
• Relies on roadway users	—	—	—	✓	✓	✓
• Provides verification	—	✓	✓	✓	—	—
• Provides two way communication	—	—	—	—	✓	—
• Allows motorist to summon assistance	—	—	—	✓	✓	✓
• Requires communications System	✓	—	—	—	✓	✓
• May require addition of equipment/vehicle by another agency	—	✓	✓	—	—	—
• Is limited during inclement weather	—	—	✓	—	—	—
• Has high initial cost	✓	—	—	—	—	—
• Provides fastest and consistent detection throughout the roadway lengths	✓	—	—	—	—	—
• Can detect major roadway blockage immediately	✓	—	—	—	—	—

5.
INCIDENT VERIFICATION

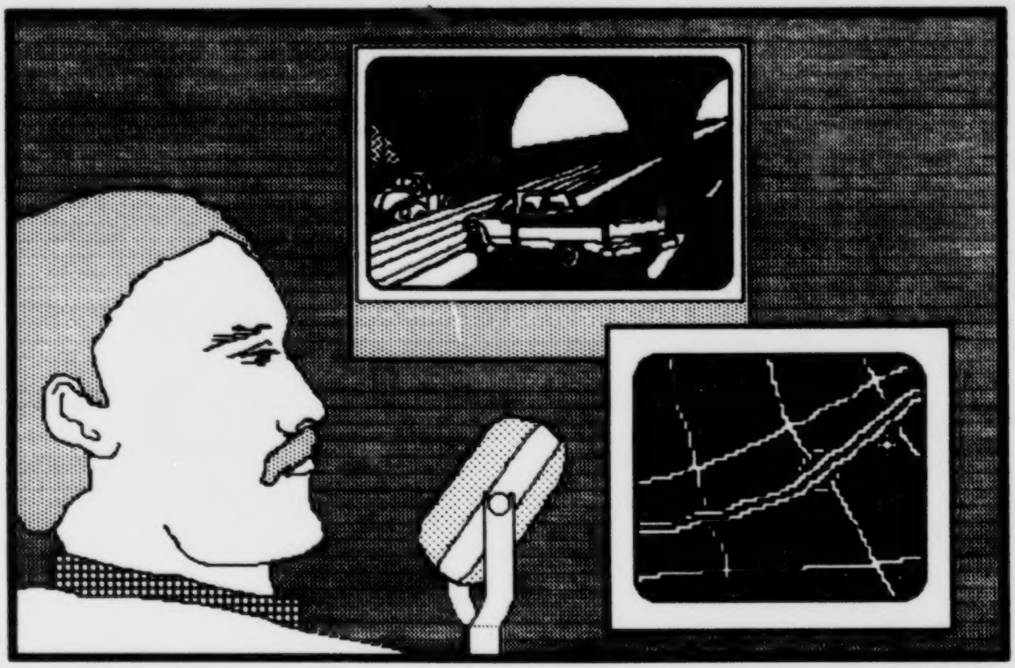


Exhibit 5a

5.1 Concept

Once an incident is detected by the incident detection system, it is important that the type of incident be determined so that the proper response can be provided. In the case where the detection has been made by direct observation by staff in patrol vehicles, or by aerial surveillance, the incident type will be automatically ascertained. However, where electronic surveillance is used, only the specific location can be pinpointed immediately —and additional techniques must be employed to verify the type of the incident. Fast incident detection, *and* fast verification, are both important so that a proper response can be quickly sent to clear up the incident (in order to reduce delays to motorists trapped behind). The following incident verification techniques will be examined in this chapter:

- television cameras;
- citizens band radio monitoring; and
- police patrols.

5.2 Techniques

Television Systems

There are several experimental projects where television cameras have been mounted at points along highway facilities. These experiments have shown that the use of television cameras is not practical as the primary surveillance method. However, T.V. cameras are being successfully used as a verification technique to determine the type of an incident once it has been detected by the electronic surveillance equipment. By turning on a camera located in the vicinity of the incident site (Exhibit 5b), a picture of the incident can be viewed on a T.V. monitor located in the central control room (Exhibit 5a). Thus, the type of incident can readily be determined and the appropriate response sent to the incident site.

While the installation costs for T.V. cameras and the actual cable transmission system have been quite high, recent technological advances (in improved resolution) do further justify their installation for (enhanced) incident verification purposes. The advantages and disadvantages of T.V. systems are summarized in Exhibit 5e.

Citizens Band Radio

The use of remote monitoring sites to communicate with C.B. radio users in the vicinity of an incident location has been recently established at several projects in the United States. Rather than listening continually to C.B. radio broadcasts via the emergency channels, or other channels, C.B. monitoring equipment has been located in cabinets at various intervals along highway facilities (Exhibit 5c). Thus, when the location of an incident is determined via the electronic surveillance system (loop detectors), the C.B. radio equipment in a cabinet located in the vicinity of the incident is turned on from the computer control centre. In this manner, the operator in the control room can listen to the broadcasts of the C.B. radios in the vicinity of the site. As the operator can also communicate with those motorists with CB radios, the type of incident can be accurately verified without leaving the control centre. The cost of installing C.B. radio monitor stations is less than the cost of installing T.V. cameras. The advantages and disadvantages of C.B. radio systems are summarized in Exhibit 5f.

Police Patrols

In order to verify the type of incident that has been detected by an electronic surveillance system, police patrols can be sent to the site of the incident (Exhibit 5d). The time to reach the site is of paramount concern. It, of course, depends heavily upon the actual location of the police patrol when notified to proceed to the incident site. Considerable time may elapse if the police patrol is caught upstream behind the incident location. In some projects, additional police patrols have been established to reduce the patrol sectors along the highway —so that the site of an incident can be reached within a reasonable time. However, the use of police patrols and the addition of patrols to provide incident verification can be considered an expensive technique due to the high labour costs, and vehicle purchase and operating costs. The advantages and disadvantages of police patrols are summarized in Exhibit 5g.

Exhibit 5b
CCTV CAMERA Field Mounting

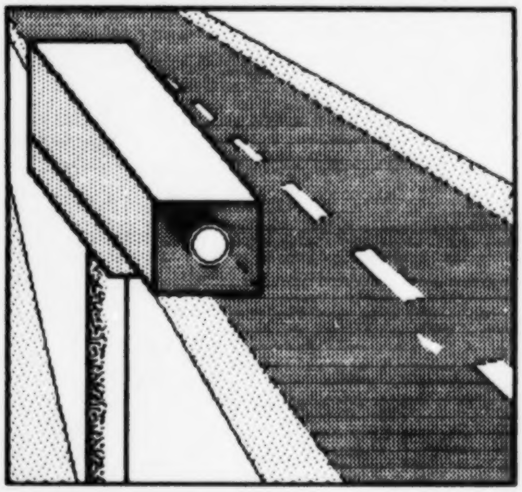


Exhibit 5c
CB RADIO MONITORING CABINET

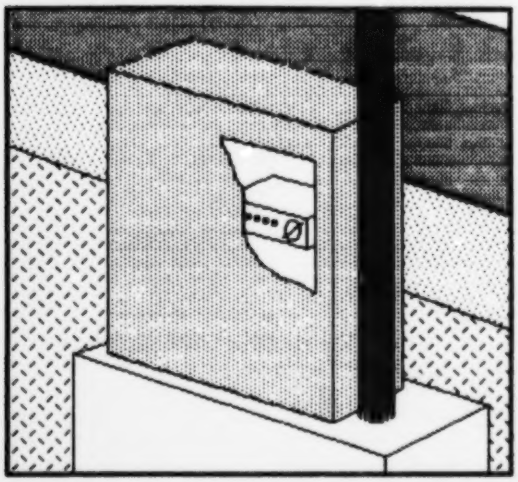


Exhibit 5d
POLICE PATROL

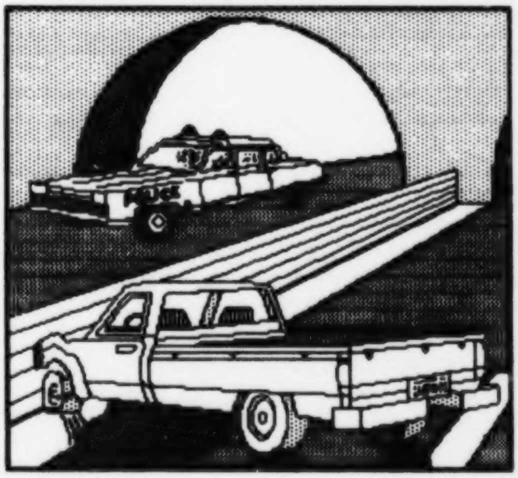


Exhibit 5e

ADVANTAGES AND DISADVANTAGES
OF
TELEVISION SYSTEMS

Advantages

- Fast visual information on the incident, and on the freeway section, to the control centre
- Dispatching of a police or other field personnel to verify incident not required
- Improved resolution of T.V. pictures due to technological advances
- Highly efficient in intensive, short length bridge/tunnel applications
- Continual viewing of monitors not required if an automatic alarm is used

Disadvantages

- High initial costs for purchase and installation of cameras, TV monitors, mounting poles and communications cables: possibly unsuitable for large systems
- High maintenance costs
- Coaxial or microwave communications system required — which may not be the existing or planned type for the overall freeway management system
- Tedious continual monitoring required unless combined with an incident alarm.

Exhibit 5f

ADVANTAGES AND DISADVANTAGES
OF
CB RADIO REMOTE MONITORING

Advantages

- Continual monitoring of CB broadcasts not required
- Dispatching of police or other field personnel to verify incident not required
- One-way (listening) and two-way voice communications capability: to quickly obtain detailed information from drivers in the vicinity of an incident
- Less expensive than a television verification system in terms of initial, maintenance, operations and communications costs

Disadvantages

- Dependant on motorists with CB radios to obtain information: possible inaccuracies
- No picture of the incident provided.

Exhibit 5g

ADVANTAGES AND DISADVANTAGES
OF
POLICE PATROLS

Advantages

- Immediate verification and police response if police vehicle spots the incident during a regular patrol
- Based on on-going police patrol operations (speed control, apprehension of violators, ...)
- Immediate emergency medical/fire response in many situations

Disadvantages

- Cost of additional vehicles and personnel, required in congested urban areas where peak hour traffic conditions may prevent seeing and reaching an incident
- Increased verification time when police vehicle is trapped without adequate emergency path (i.e. shoulders), in traffic behind the incident.

5.3 Equipment

The primary components of a closed circuit television camera system are:

- TV cameras mounted on poles or existing structures (buildings, overpasses, etc.) at field locations
- TV camera accessories, including a pan (horizontal movement) and tilt (vertical movement) assembly
- TV monitors in the centralized computer control room
- peripheral devices (video tape recorders)
- communications devices (coaxial cable or microwave transmission) to link field sites to the control centre.

The primary components of a citizens band radio monitoring site system are:

- field cabinet and foundation
- field antenna
- CB radio equipment and interface equipment in the field cabinet
- communications equipment
- CB radio receiver/transmitter in the control centre.

The primary components of a police patrol system are:

- police vehicles patrolling the freeways
- police communications radio
- various emergency aid equipment in the vehicles
- police communications equipment in the control centre.

5.4 Cost Components

Approximate costs for the three incident verification techniques are presented in Exhibit 5h.

Exhibit 5h

COSTS OF INCIDENT VERIFICATION TECHNIQUES

COMPONENT	COST
CCTV System[1]	$
• Field camera unit with pan and tilt assemblies	15 000.
• Camera pole	5 000.
• Field control cabinets	800.
• TV monitor in control room	600.
• Video tape recorder in control room	2 000.
• Camera control unit in computer room	12 000.
Citizens Band Radio Remote Monitoring	
• Field cabinet and foundation[2]	—
• Field antenna with PVC shield	30.
• CB radio equipment and field interface equipment	100.
• CB radio receiver/transmitter in control centre	70.
• Dial-up phone communications ($ per month per field location)	20.
Police Patrol System	
• Police vehicle with communications radio	20 000.
• Police officer[3]	30 000.
• Police communication equipment in control centre[4]	300.

Notes:

1. See Chapter 15 for cost of coaxial communications cable.
2. As part of a freeway management system, it is assumed that an existing field cabinet will be used to house the CB radio field equipment. Thus, no costs are assigned to the field cabinet and foundation.
3. Assumes one police officer for 8 hours/day. If 24 hour operation is required for incident verification, it should be anticipated that five police officers will be required per day to cover shifts, vacations, etc. Appropriate overhead costs should also be added.
4. This component may be installed as part of the interfacing of the control centre with the police operating agency as part of the overall freeway management system instead of a separate cost to be assigned to the incident verification system.

5.5 Application Criteria

In comparing the applicability of alternative incident verification systems to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 5i:

Exhibit 5i

APPLICATION CRITERIA FOR INCIDENT VERIFICATION SYSTEMS

	ALTERNATIVE SYSTEMS		
APPLICATION CRITERIA	CCTV	CB Radio Remote Monitoring	Police Patrol
System Configuration			
• High accident spot locations	✓	✓	✓
• Bridges & tunnels	✓	—	✓
• Long lengths of roadways	—	✓	✓
Verification Time			
• Fastest overall	✓	✓	—
Environmental Conditions			
• Effective under adverse weather conditions of fog & heavy rain	—	✓	✓
Initial Costs			
• Highest	✓	—	—
• Medium	—	—	✓
• Lowest	—	✓	—
Operating Costs			
• Highest	✓	—	—
• Medium	—	—	✓
• Lowest	—	✓	—
Operational Features			
• Visual information provided	✓	—	—
• Dispatching of personnel required to verify incident	—	—	✓
• Alarm system can be utilized to initiate incident verification	✓	✓	✓
• Immediate police/emergency response results	—	—	✓
• Unaffected by the requirement to perform another function (e.g. police patrols perform traffic enforcement)	✓	—	—

6.
INCIDENT RESPONSE

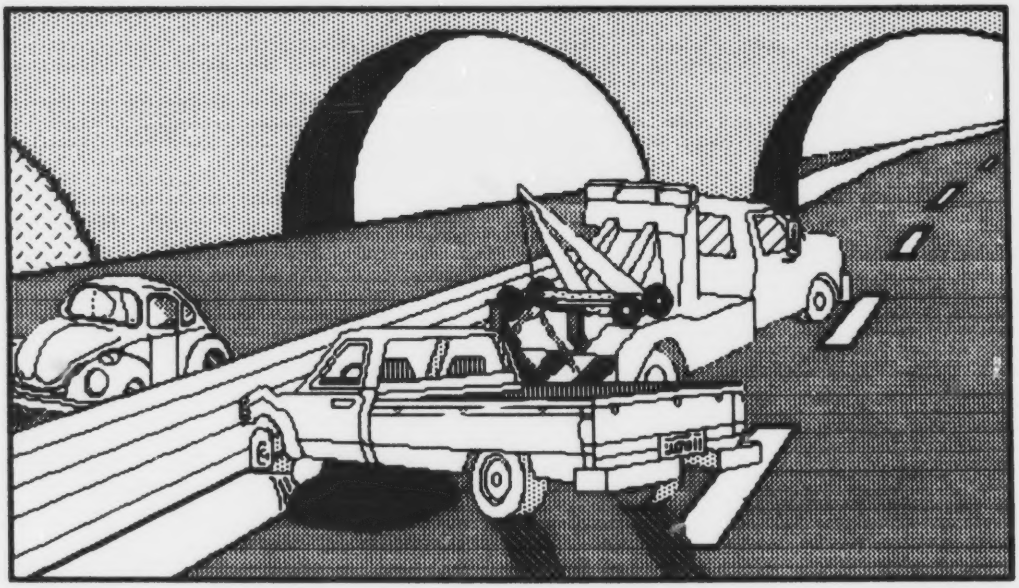


Exhibit 6a

6.1 Concept

Once an incident is detected by the incident detection system, and the type and severity of the incident are determined by the incident verification system, it is necessary to send the appropriate emergency response vehicles to the site of the incident — to provide any necessary emergency services and to undertake the removal of the vehicle(s) and clearance of the incident site.

To expedite the response process, the various types of emergency vehicles can be directed to "rove" or travel in the traffic stream during the a.m. and p.m. peak periods. In this manner, they will also be able to perform the functions of incident detection and verification. The accomplishment of fast incident detection, verification and response, will benefit the motorists by reducing delays and by returning the roadway to "normal" traffic conditions as quickly as possible.

There are four primary alternative incident response techniques:

- Courtesy patrols
- Police cars
- Tow trucks
- Heavy duty equipment

Information on these alternative techniques is presented in the following.

6.2
Techniques

Courtesy Patrols
Courtesy patrol vehicles have equipment which will permit their drivers to provide assistance in minor vehicle problems and breakdowns. They can provide:

a) a few litres of gasoline or diesel fuel for vehicles that have run out of it;
b) battery jumps for vehicles whose batteries are dead;
c) tire changing equipment for vehicles who may not have a jack or whose lug nuts are too tight to be able to be loosened, etc.

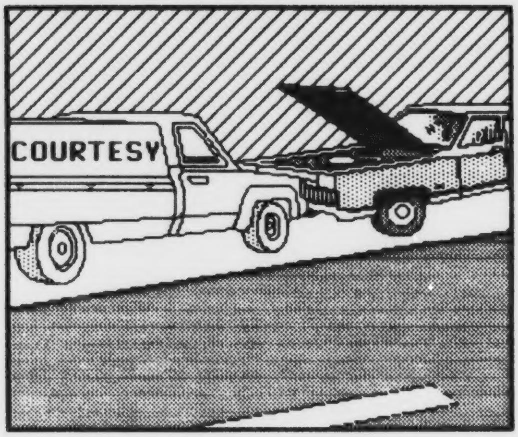
The advantages and disadvantages of courtesy patrols are presented in Exhibit 6c.

Police Cars

Police cars patrolling the freeways and expressways can also be equipped to provide minor assistance to motorists. They can also be equipped with heavy duty bumpers, which will permit them to push to the side passenger vehicles which are broken down within the roadway lanes. This will reduce the duration of lane blocking situations and the consequent delays to other motorists. (Exhibit 6d). The advantages and disadvantages of using police patrols for incident response are presented in Exhibit 6e.

Exhibit 6b

COURTESY PATROL VEHICLE



Tow Trucks

Tow truck services on freeways and expressways should be established by specific sections (of appropriate length) so that the desired response times can be obtained. Five minutes for the tow trucks to travel from their permanent station or garage to the site of an incident is considered desirable. (Exhibit 6f).

In order to select between a system that utilizes agency owned tow truck equipment and a system that franchises the tow truck operation to private companies, the following factors should be considered:

a) initial cost of the vehicles;
b) labour costs of the drivers;
c) recurrent costs;
d) method of storing vehicles that are towed from the highway facilities;
e) capability of meeting the response time requirements.

In addition, the need for light duty versus heavy duty tow trucks should be determined — so that the proper response vehicles can be available and dispatched to handle incidents involving passenger vehicles as well as tractor trailers carrying heavy loads. The advantages and disadvantages of tow trucks as response vehicles are presented in Exhibit 6g.

Exhibit 6c

ADVANTAGES AND DISADVANTAGES OF COURTESY PATROLS

Advantages

- Assistance for minor problems and breakdowns
- Quick removal of disabled vehicles
- Regular, frequent assistance on highways
- Accurate incident verification (once on site) — and occasional detection
- Reduction in "rubbernecking" delays: by reducing response time to get motorist on the move.
- Some revenue to agency (if operations franchised)

Disadvantages

- Costs for equipment and personnel (if agency operated)
- Many lane blockages not removeable.

Exhibit 6d

POLICE VEHICLE CLEARING ROADWAY

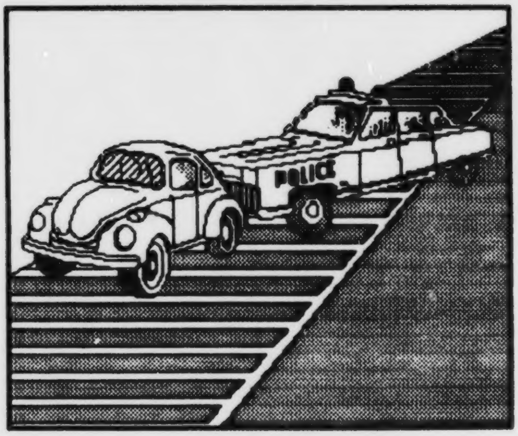


Exhibit 6f

TOW TRUCK SERVICE

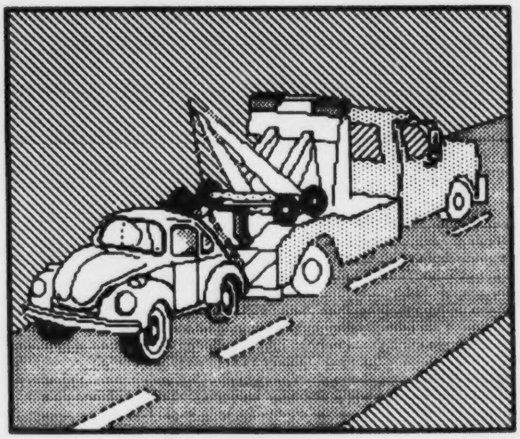


Exhibit 6e

ADVANTAGES AND DISADVANTAGES OF POLICE CARS

Advantages

- Built on existing (patrol) presence on the freeway
- Overall incident management aided by law enforcement presence
- Accurate incident verification (once on site)
- Based on established (police) communication system
- Removal of disabled vehicle from travel lanes (when police vehicle equipped with heavy duty bumper)

Disadvantages

- Primary (law enforcement) responsibilities may distract from incident response
- More costly than other methods (if an adequate number of patrols provided)

Exhibit 6g

ADVANTAGES AND DISADVANTAGES OF TOW TRUCKS

Advantages

- Ability to clear most incidents from the roadway
- Low cost to the agency (with franchised operation)

Disadvantages

- Costly to purchase and operate (if agency owned)
- Contracting and management must assure compliance with operational standards.

Heavy Duty Equipment

Since truck spills and tractor trailer accidents may occur, the need to provide heavy duty tow equipment should be examined. Heavy duty equipment can range from large size cranes to specially modified or designed emergency response vehicles. The advantages and disadvantages of heavy duty equipment are presented in Exhibit 6i.

Exhibit 6h

SPECIAL HEAVY DUTY EQUIPMENT

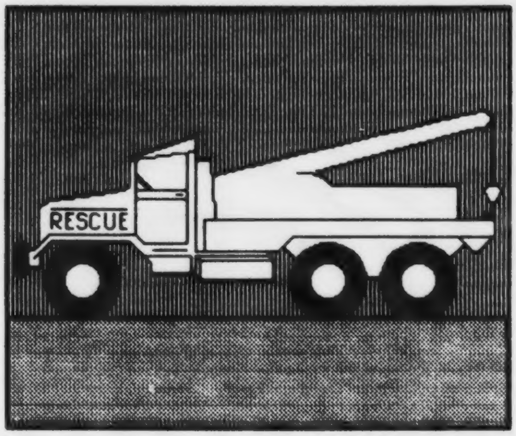


Exhibit 6i

ADVANTAGES AND DISADVANTAGES
OF
HEAVY DUTY EQUIPMENT

Advantages

- Ability to clear all major incidents
- Quick response to incidents

Disadvantages

- Extremely costly to purchase and operate
- Used only infrequently: does not normally provide sufficient revenue to cover costs
- Suitable primarily for short freeway sections with very high utilization (such as tunnel or bridge).

6.3
Equipment

The primary elements of an incident response system are the incident response vehicle and the equipment it is capable of carrying (Exhibit 6j).

Exhibit 6j
INCIDENT RESPONSE EQUIPMENT

TYPE OF RESPONSE VEHICLE	AUXILIARY EQUIPMENT
Courtesy Patrol (Van or Station Wagon)	Two-way radio Flashing hazard lights Cones Flares Compressed air Water Gasoline Jumper cables Tools First aid kit Jack Tow chain
Police Car	Police radio Flashing hazard lights Flares First aid kit Push bumpers
Tow Truck	Two-way radio Flashing hazard lights Cones Flares Compressed air Water Gasoline Jumper cables Tools
Heavy Duty Equipment	Two-way radio Flashing hazard lights Cranes & lifts Major catastrophe equipment

6.4 Cost Components

Approximate costs for implementing each of the four incident response techniques are presented in Exhibit 6k.

Exhibit 6k

COSTS OF INCIDENT RESPONSE TECHNIQUES

COMPONENT	COST ($)
Courtesy Patrols	
• Agency owned patrols	
— Vehicle	16 000
— Drivers[1]	48 000 per year
— Maintenance & Operations	8 000 per year
• Franchised patrols[2]	N/C
Police Cars	
• Vehicle and officer[3]	55 000
Tow Trucks	
• Agency owned	
— Vehicle	20 000
— Drivers[4]	40 000 per year
— Maintenance & Operations	8 000 per year
• Franchised tow trucks[2]	N/C
Heavy Duty Equipment	
• Agency owned	
— New heavy duty	100 000
— Modified equipment[5]	20 000
— Driver	48 000 per year
— Maintenance & Operations	10 000 per year

Notes:

[1] Assumes salary of one driver of approximately $24 000 per year. Thus, to cover a.m. & p.m. peak periods, 2 drivers at a minimum would be required for one courtesy patrol vehicle.

[2] For a franchised operation, there is no cost to the transportation agency.

[3] Assumes one (1) police officer for 8 hours/day. If 24 hour operation is required, it should be anticipated that five (5) police officers will be required per day to cover shifts, vacations, etc. Appropriate overhead costs should also be added. Assumes police vehicle cost is $10 000 + equipment, and officer salary is $30 000 per year.

[4] Assumes 2 drivers at annual salary each of $20 000.

[5] Assumes a modified army surplus vehicle adapted for highway use and wrecker equipment.

6.5

Application Criteria

In comparing the applicability of alternative incident response techniques to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 6I.

Exhibit 6I

APPLICATION CRITERIA
FOR
INCIDENT RESPONSE TECHNIQUES

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS			
	Courtesy Patrol	Police Patrol	Tow Truck	Heavy Duty Equipment
Performance Characteristics				
• Provides regular patrols	✓	✓	✓	
• Provides incident verification	✓	✓	✓	
• Provides services to stranded motorist	✓		✓	
• Can remove most incidents from roadway			✓	✓
• Can remove largest vehicles from roadway				✓
Type of Incident				
• Motorist out of gas	✓	✓	✓	
• Repair of flat tire	✓	✓	✓	
• Pushing disabled vehicle to shoulder	✓	✓	✓	
• Towing disabled vehicle			✓	✓
• Towing large truck or tractor trailer				✓
• Removing large obstacles from roadway				✓

7.
BRIDGE/TUNNEL SURVEILLANCE SYSTEMS

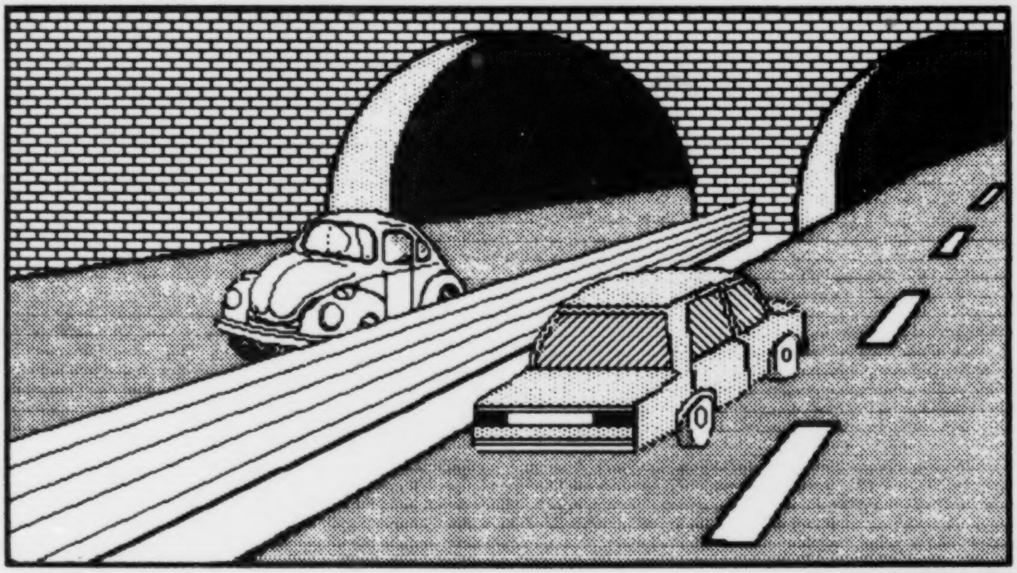


Exhibit 7a

7.1 Concept

Installations consisting of a variety of freeway control equipment at bridges and tunnels are often categorized as specialized surveillance and control systems. The LaFontaine and Ville Marie tunnels in Montreal and the Lincoln and Holland tunnels across the Hudson River in New York have such extensive installations. Construction of a specialized system for the Burlington Skyway in Ontario is underway.

Due to the very high costs, many existing bridges and tunnels were constructed with less travel lanes than the adjacent highway sections, and were often left without any shoulders available for emergency response vehicles or disabled vehicles. As a result, when an incident occurs at such a facility, traffic problems are often exacerbated due to:

- difficulties encountered by emergency response vehicles in reaching the site of the incident;
- the inherent bottleneck characteristic of the facility, which creates additional long lines of vehicles behind the incident; and
- the lack of diversion opportunities in the vicinity of the facility.

Due to the occurrence of these various traffic problems, specialized freeway management systems are being installed as an integral part of the construction of new bridge and tunnel facilities at many locations. Such systems provide virtually instantaneous incident detection, verification, and a quick response capability — thereby lessening delays imposed on the motorists.

7.2 Techniques

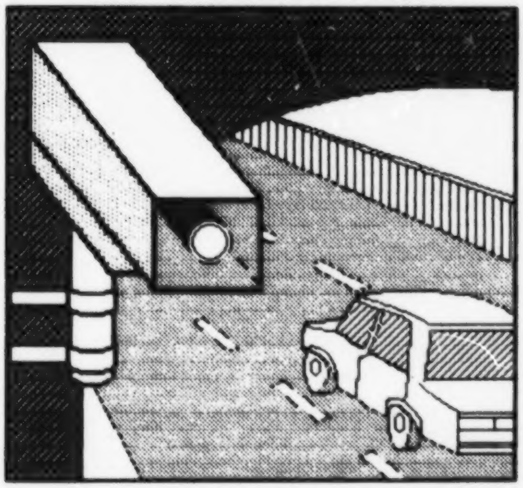
Because bridges and tunnels are typically very short compared to the overall lengths of freeway facilities, it is usually possible to install an extensive 'package' of various monitoring and control devices and support systems at a comparatively low cost. This is also often made financially possible by the fact that many authorities are autonomous, and can provide funding through the collection of tolls at these facilities.

The various types of alternative techniques which can be implemented at bridge and tunnel (point) facilities are presented in the following:

Closed Circuit T.V.

Closed circuit television cameras can be mounted along various sections of a bridge or a tunnel in order to detect incidents and to verify their cause and location (Exhibit 7b). At many facilities, a corresponding number of television monitors have been mounted along a wall section to permit continuous viewing of all (camera) locations by an operator in the control centre. However, a single T.V. monitor can also be used. It can be programmed or manually commanded to scan each of the sections of the roadway viewed by each field mounted camera, so that the operator does not have to look at each individual T.V. screen. When installed with inductance loop detectors, the incident detection system will advise of the specific location of a breakdown so that the T.V. monitor(s) can be utilized to verify the specific needs of the motorist(s) involved in the incident. In addition, television cameras can be mounted off the bridge or outside of a tunnel so that information can be obtained on the traffic conditions beyond the limits of the point facility. The advantages and disadvantages are summarized in Exhibit 7c.

Exhibit 7b
CCTV CAMERA MOUNTING



Inductance Loops

Inductance loops on bridges and tunnels are usually installed with close spacings. The shorter distances between the loop stations will provide faster incident detection times and quicker incident management times. The advantages and disadvantages are summarized in Exhibit 7d.

Increased Police Activities

Increased police activities may be initiated during peak periods of operation of a bridge or tunnel facility. Police officers may be stationed on the bridge or inside the tunnel at key points so that they can provide information via two-way radio communications with the control centre. (Exhibit 7e). Special vehicles have been designed to permit access, in some tunnels, to police patrols along the catwalks (Exhibit 7f). In this manner, one police officer can safely reach incident locations and provide immediate traffic control. At other tunnel operations, additional police officers are utilized, particularly during the a.m. and p.m. peak periods, to assist in the management of incidents. These police officers are stationed inside the tunnel and at the entrances and exits of

Exhibit 7c

ADVANTAGES AND DISADVANTAGES
OF
CCTV SYSTEMS AT POINT FACILITIES

Advantages
- Picture of incident scene viewable at control centre
- Relatively low cost compared to systems for long highway sections
- Overall time for incident management reduced

Disadvantages
- Increased maintenance in tunnel sections: to clean up camera units of build up of dirt and chemicals in exhaust fumes
- Special mounting on bridges: to prevent vibrations

the tunnel. The advantages and disadvantages of increased police activities are summarized in Exhibit 7g.

Exhibit 7d

ADVANTAGES AND DISADVANTAGES
OF
CLOSELY SPACED DETECTORS

Advantages

- Reduced incident detection time
- Reduced overall incident management time
- Maintenance and repair less urgent due to availability of information from immediately adjacent detectors

Disadvantages

- Metallic interferences to loop detectors on some bridges

Exhibit 7e
TUNNEL SURVEILLANCE BOOTH

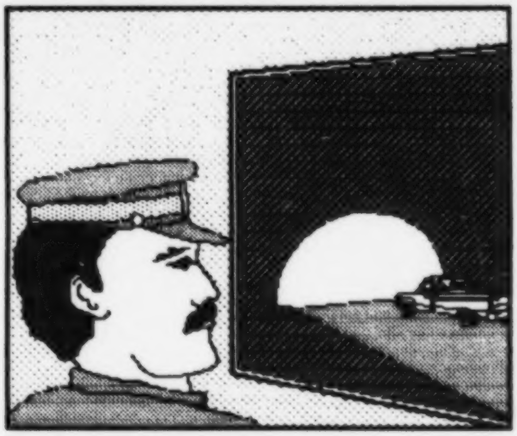


Exhibit 7f
CATWALK VEHICLE

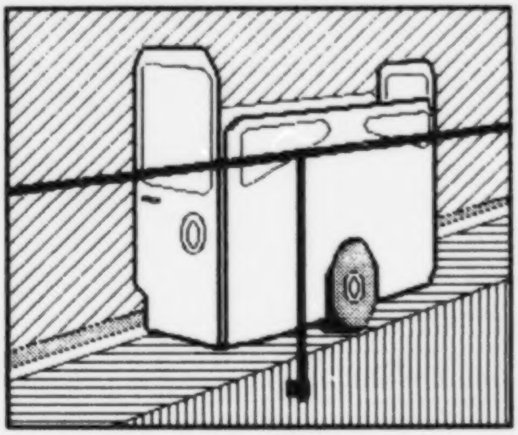


Exhibit 7g

ADVANTAGES AND DISADVANTAGES
OF
INCREASED POLICE ACTIVITIES

Advantages

- Improved incident handling capability
- Better adherance to recommended speeds
- Assurance to motorists that assistance is readily available in case of breakdowns or emergency situations
- Immediate enforcement of traffic control measures
- Faster response through use of special vehicles on catwalks (also less officers overall)

Disadvantages

- Additional personnel costs
- Enhanced environmental setting and/or booth and/or vehicles required for safe operation by the police

Emergency Response Vehicles

Many bridge and tunnel authorities have started to station tow trucks on "continuous call" at the entrances and exits of their facilities during peak travel periods (Exhibit 7h). The establishment of these patrols is aimed at providing a fast response to incidents and restoring the traffic flow as soon as possible to its pre-incident condition. Some of these emergency response vehicles are specially designed to tow broken down tractor trailer units. Several emergency operations are based on responding through the exit of the facility — so that the tow trucks enter against the flow of traffic at times when the bridge or tunnel is completely blocked. The advantages and disadvantages of continuous call tow truck operations are summarized in Exhibit 7i.

Exhibit 7h

EMERGENCY RESPONSE VEHICLES

Continuous-Call Positioning

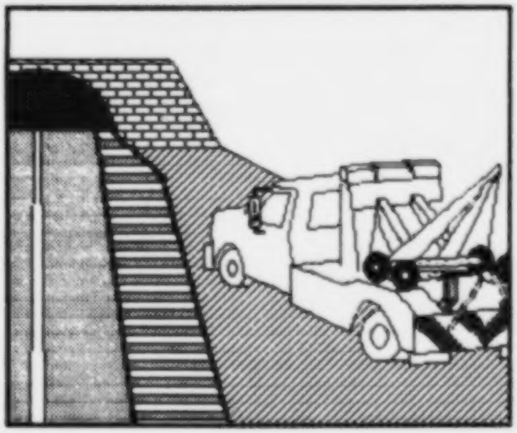


Exhibit 7i

**ADVANTAGES AND DISADVANTAGES
OF
EMERGENCY RESPONSE VEHICLES**

Advantages

- Reduced incident response time
- Reduced overall clearance time: traffic flow quickly restored to its "normal" condition

Disadvantages

- Additional personnel required to operate the vehicles
- Capital cost to purchase the vehicles (if owned by the operating authority)

Traffic Control Signals and Variable Message Signs

Overhead traffic signal lane designation controls can be utilized on a bridge or within a tunnel to reverse the travel lanes during the peak hours. Red "X"s will be displayed to indicate that a travel lane is closed for that direction of travel while a green down arrow would indicate that the lane can be used. (Exhibit 7j). The use of these special traffic signal lane controls will also permit emergency response vehicles to enter from the end of the facility in the "wrong direction" to reach the location of an incident. Various types of variable message sign systems have also been utilized to prevent congestion on bridges or in tunnels by:

- stopping vehicles before entering the facility thereby creating an additional metering effect; and
- advising of speeds and conditions on and within the point facility. (Exhibit 7k).

The advantages and disadvantages of this technique are summarized in Exhibit 7l.

Around-the-Clock Operations

Many tunnels which function as entrances to metropolitan central business districts have expanded their staffing to cover 24 hours per day, seven days per week. It is expensive to provide, on an around-the-clock basis, trained personnel who are also *experienced* in handling all required traffic management functions and capable of responding to full range of possible incidents and emergencies. However, in major travel corridors — with complex (7-day) mix of commuting, recreational, tourism, shopping, etc. travel — it is highly desirable to provide around-the-clock staffing at the control centre. For full response capability, the control centres of adjacent bridges and tunnels must be connected with communications systems, and joint (diversion) response strategies developed.

Exhibit 7j

OVERHEAD LANE CONTROL SIGNALS

Point Facility

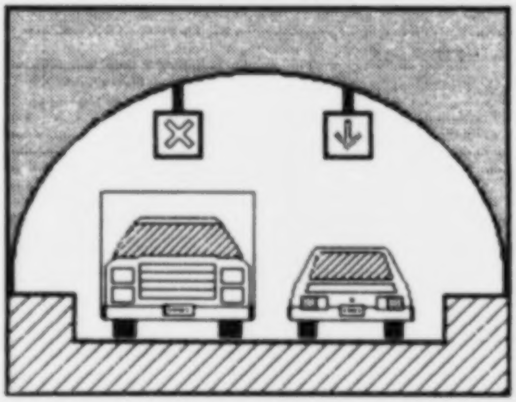


Exhibit 7k

VARIABLE MESSAGE SIGN

Point Facility

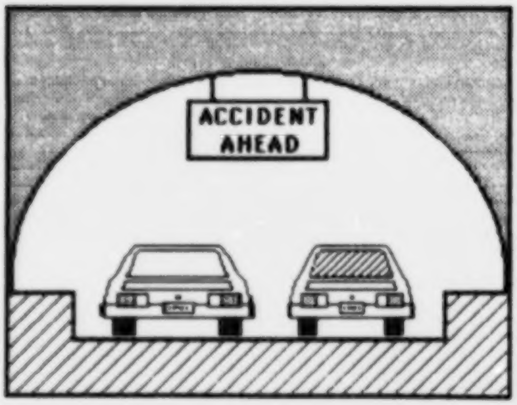


Exhibit 7l

ADVANTAGES AND DISADVANTAGES OF TRAFFIC CONTROL SIGNALS AND VARIABLE MESSAGE SIGNS

Advantages
- Capability for reversible lane operation: to match capacity to directional (commuter) peak flows
- Real-time information to the motorists concerning traffic conditions and recommended speeds
- Capability for preferential treatment of HOVs

Disadvantages
- Significant costs for installation of variable message sign systems
- Continual maintenance and operating costs: to ensure uninterrupted control and response capability
- Use limited to incident response (once peak directional person flows roughly equal)

Special Instrumentation

As part of an overall traffic management system for a bridge or tunnel facility, special instrumentation may be installed in order:

- to warn of unique conditions when vehicles should not enter the facility; and
- to prevent vehicles from entering the facility.

At one bridge location, special instrumentation has been installed to the piers. They are designed to detect vibrations which would result from a ship hitting the pier and possibly severely damaging the bridge — resulting in vehicles plunging into the water. At another bridge, specially designed gates have been installed to prohibit vehicles from entering a section of the facility during an unusual event (such as the collision of a boat with a bridge pier).

7.3 Equipment

The primary components of a closed circuit television camera system are:

- TV cameras mounted on the bridge structure or within the tunnel, as well as at the entrance and exit sections (of the highway)
- TV camera accessories, including a pan (horizontal movement) and tilt assembly
- TV monitors in the centralized computer control room
- peripheral devices (video tape recorders)

- communications devices (coaxial cable or microwave transmission dishes) to link field sites to the control centre.

The primary components of a closely spaced loop system are:

- detectors (inductance loops or other types) at intervals of roughly 240m-360m
- loop detector amplifier (one amplifier may monitor up to four loops on individual channels)
- field cabinet to house amplifiers and communications equipment
- communications system to link the field site to the control centre
- central processing facility, where a computer software program processes either raw or pre-processed field data and determines the roadway operating characteristics.

The primary components of increased police activities are:

- police officers equipped with two-way communications radios
- police communications equipment in the control centre
- police booths or stations (as a protection from the environment) on the bridge or in the tunnel
- special police vehicles which are designed to operate on the catwalks of the bridge or the tunnel.

The primary components of an emergency response system are:

- tow trucks and drivers, on continuous call, stationed at the entrances and/or exits of the facility during peak travel periods
- specially designed tow vehicles to remove broken down tractor trailer units off of the bridge section or out of the tunnel section
- two-way communications radio linkage to the control centre.

The primary system components of a traffic control signal and variable message sign system are:

- overhead traffic signal lane designation controls
- variable message signs
- field cabinets
- communications to link the field site to the control centre
- related equipment located in the control centre.

The primary components of around-the-clock operations are:

- additional trained personnel.

The primary components of the special instrumentation devices are:

- vibration detectors on piers of a bridge
- special gates which will prohibit traffic from entering a section of the point facility
- field cabinets to house the field and communications interface equipment
- communications to link the field site to the control centre.

7.4 Cost Components

The primary cost information on the various components of the bridge/tunnel surveillance systems has been provided in other chapters as follows:

- Closed Circuit TV — Chapter 5: Incident Verification
- Inductance Loops — Chapter 4: Incident Detection
- Increased Police Activities — Chapter 5: Incident Verification
  Costs for a police vehicle with communications radio, a police officer, and police communication equipment in the control centre are provided. No cost information was readily available on the design of special vehicles to operate on the catwalks. The costs will be related to the geometric requirements and characteristics of each specific bridge or tunnel facility.
- Emergency Response Vehicles — Chapter 6: Incident Response
- Traffic Control Signals and Variable Message Signs — Chapter 10: Driver Information Signing
- Around-the-clock Operations — The costs will vary depending upon the number and experience of personnel required. Approximate salaries for three main personnel classifications are:

— police officer	— $30 000/per year
— technician	— $12 000/per year
— senior engineer	— $40 000/per year

At facilities where one staff member (of a classification) is required for each eight hour shift, five people of that classification will be required per day to cover all shifts, vacations, etc. In estimating total costs, appropriate overhead multipliers should be used with the salaries indicated above.

- Special Instrumentation — No cost information has been readily available. The costs will depend largely upon the length of the structure, the number and location(s) of the installations, and on the sensitivity and specialty of the devices installed.

7.5 Application Criteria

In comparing the applicability of alternative bridge/tunnel surveillance techniques to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 7m.

Exhibit 7m
APPLICATION CRITERIA
FOR
BRIDGE/TUNNEL SURVEILLANCE TECHNIQUES

APPLICATION CRITERIA	ALTERNATIVE SURVEILLANCE TECHNIQUES					
	CCTV	Incident Loops	Increased Police Activity	Emergency Response System	Lane Control VMS	24 Hour Operation
Incident Detection						
• Senses incidents automatically	—	✓	—			
• Depends on regular patrols	—	—	✓			
• Provides verification	✓	—	✓			
• Requires communications system	✓	✓	—			
• May require additional vehicles or specialized equipment	—	—	✓			
Incident Response & Management						
• Provides manpower for handling incidents			✓	✓	—	✓
• Provides ability to close lanes			✓	—	✓	—
• Provides enforcement of traffic control measures			✓	—	—	—
• Provides for removal of lane blockage by stalled vehicles or vehicular accident			—	✓	—	—
• Requires additional personnel			✓	✓	—	✓

8.

RAMP METERING SYSTEMS

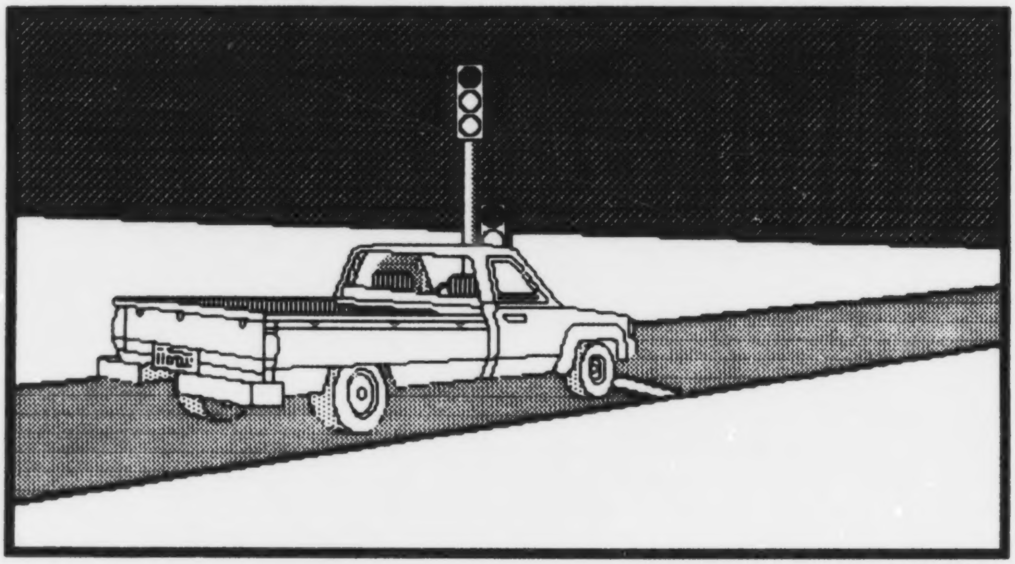


Exhibit 8a

8.1 Concept

At times, a motorist can be caught in stop-and-go traffic that appears to be caused by an incident downstream. However, as the motorist travels downstream, the speed of the traffic increases and no incident is observed. This situation often occurs daily in the vicinity of entrance ramps. This type of recurrent congestion is caused by the demand to use the roadway facility exceeding the capacity of the roadway.

At such ramp locations, it is often possible to manage the vehicular demands through metering. By controlling the rate at which the vehicles can enter onto the mainline of the freeway, a more even traffic flow can be maintained. Stop-and-go congestion, which results from the shear volume of vehicles entering from the ramp (and taking a slot in the main flow) and from main line vehicles changing from the right lane to the centre lane(s) prior to the ramp, can be often significantly reduced. Also, the vehicles on the ramp — once released by the metering station — can each join the main line flow more smoothly and safely.

There are three main ramp metering techniques, which are being utilized at the present:

- fixed time metering;
- traffic responsive metering; and
- system responsive metering.

Information on these three alternative techniques is presented in the following.

8.2 Techniques

Fixed Time Metering

In fixed time ramp metering the traffic signal (which is located on the entry ramp — Exhibit 8a) holds and releases vehicles in accordance with a pre-timed (or fixed) metering rate. In most cases, the signal operates at different cycle lengths depending on the time of the day — to optimize the traffic flows during the a.m. and p.m. peak periods, and during the 'shoulders' of the peaks. In addition to the time of day operation, metering rates can be fixed by the time clock for the various days of the week.

The fixed time metering rates are based on historical data relating the ramp flows to the demand and capacity of the freeway.

The advantages and disadvantages of fixed time ramp metering are summarized in Exhibit 8b.

Traffic Responsive Metering

In traffic responsive ramp metering, the metering rates are continually adjusted on the basis of real-time traffic conditions. When detectors on the mainline of the freeway indicate that traffic is very heavy, the metering rates will be automatically adjusted so that vehicles will be required to stop at the ramp signal for several seconds before they are released for entry into the main traffic stream. Similarly, when traffic volumes are light on the mainline of the freeway, the metering rates will be adjusted so that vehicles only need to make a quick stop before entering the freeway. The metering rates will be established based on the actual mainline traffic flow conditions, the ramp volumes, and the capacity of the freeway section.

The advantages and disadvantages of traffic responsive ramp metering are summarized in Exhibit 8c.

System Responsive Metering

System responsive metering combines individual ramps into a system so that the metering rates of the individual ramps can be established to maximize the mainline traffic flow.

In order to provide for system responsive metering, an interconnection/communications system is required to link the individual ramps to a central computer.

The advantages and disadvantages of system responsive ramp metering are summarized in Exhibit 8d.

Exhibit 8b

ADVANTAGES AND DISADVANTAGES
OF
FIXED TIME METERING

Advantages

- Single ramp installations possible
- Several ramps can be interconnected into a metering system
- Simple form of control
- Reduced congestion and mainline delays (compared to "No Control" situation)

Disadvantages

- Not responsive to the actual traffic conditions on the freeway:
  - — rate not adjusted to match (random) volume fluctuations
  - — may meter when not necessary (based on traffic conditions)
- Not responsive to non-recurrent congestion (caused by incidents, maintenance and construction activities, and special events).

Exhibit 8c

ADVANTAGES AND DISADVANTAGES
OF
TRAFFIC RESPONSIVE METERING

Advantages

- Single ramp installations possible (can be installed at an individual ramp to provide improvements to the operations of the mainline of the freeway)
- Interconnections possible: a series of ramps in a ramp metering system
- Responsive to the actual traffic conditions on the freeway
- Responsive to non-recurrent congestion (resulting from incidents, maintenance and construction activities, and special events)

Disadvantages

- Additional detectors required on the mainline: to determine upstream and downstream conditions
- More sophisticated form of control required (than in fixed metering)

Exhibit 8d

ADVANTAGES AND DISADVANTAGES
OF
SYSTEM RESPONSIVE METERING

Advantages

- Mainline traffic flow maximized: by establishing appropriate metering rates at individual ramps
- Responsive to the actual traffic conditions throughout the freeway length controlled
- Responsive to non-recurrent congestion (resulting from incidents, maintenance and construction activities, and special events)

Disadvantages

- More sophisticated form of control required (than in fixed time or taffic responsive metering)
- Interconnection/communications system required: to link the individual ramps to a central computer
- Central computer required: to analyze field data and to establish metering rates of individual ramps
- Higher cost than for fixed time or traffic responsive metering

8.3
Equipment

The primary components of a ramp metering system are:

- ramp signals
- detectors
- ramp signing
- ramp controller
- communications linkage
- central computer

The first four components are required for fixed time and traffic responsive metering systems. The latter also requires additional detectors on the freeway mainline lanes, so that information on real-time traffic conditions can be obtained. The communications linkages and the central computer are required for system responsive metering installations.

Two section signal heads (to display red and green indications) are commonly utilized — however, three section signal heads (to display red, yellow and green indications) are also sometimes used. Two ramp signal heads are used either by locating:

- a pedestal-mounted signal head on each side of the ramp; or
- two signal heads at two different heights on one signal pole on the left side of the ramp (Exhibit 8e). A flashing beacon sign assembly to advise that the ramp is metered is illustrated in Exhibit 8f.

Exhibit 8e
TYPICAL RAMP METERING SIGNAL

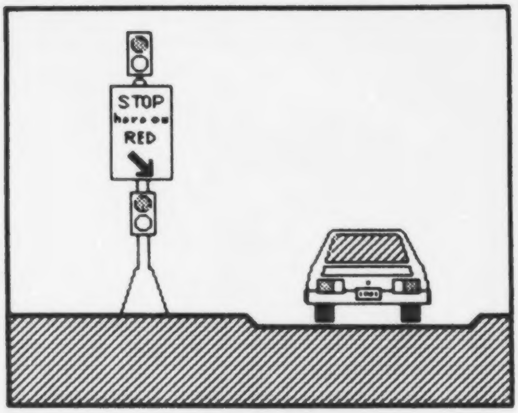
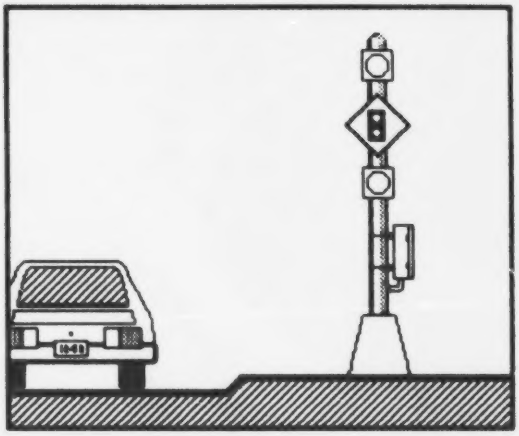


Exhibit 8f
FLASHING BEACON SIGN ASSEMBLY

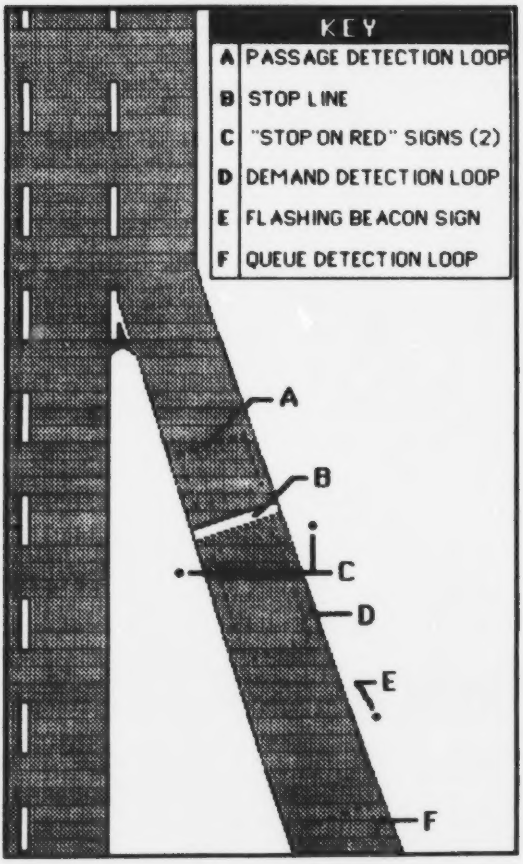


The following three loop detectors are generally installed at a metered ramp (for a schematic presentation, see Exhibit 8g):

- A "demand" detector immediately upstream of the ramp metering signal stop line — to detect the presence of a vehicle at the ramp signal and to initiate the metering cycle;
- A "passage" detector immediately downstream of the stop line — to assure that the next green signal indication is not displayed until the previous vehicle has cleared the metering location; and
- A "queue" detector upstream, either near the ramp entrance or on the adjacent street — to detect when excessive backups occur on the ramp which may interfere with traffic flow on the adjacent street. When this situation occurs, ramp metering rates are increased to shorten the queue length.

The ramp controller can be either a solid state ramp controller or a 170 type microprocessor.

Exhibit 8g
SCHEMATIC OF RAMP METERING STATION



The signing on ramps may consist of:

a) an advance warning sign (with or without flashing beacons) to warn motorists that the ramp is metered;
b) a sign to advise the motorist to stop at the stop line next to the ramp meter signal ("stop here on red") so that the vehicle stops close enough for the demand detector to note its presence.

8.4 Cost Components

Approximate costs for installing a fixed time, a traffic responsive and a system responsive metering system at one ramp location, are presented in Exhibit 8h.

8.5 Application Criteria

In comparing the applicability of alternative ramp metering techniques to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 8i.

Exhibit 8h

APPROXIMATE COSTS FOR ALTERNATIVE RAMP METERING SYSTEMS

COMPONENT	FIXED TIME	TRAFFIC RESPONSIVE	SYSTEM RESPONSIVE
	($)	($)	($)
• Detectors			
— Ramp	1 000*	1 600[3]	1 600[3]
— Mainline	—	1 600[3]	1 600[3]
• Signal Heads[2] (2 section head)	1 000	1 000	1 000
• Signal Poles and Foundations[2]**	3 000	3 000	3 000
• Ramp Controller			
— Solid State with cabinet	3 500	3 500	3 500
— 170 Microprocessor with cabinet	4 000	4 000	4 000
• Conduit ($60/m)	420[7m]	2 000[33m]	2 000[33m]***
• Pullboxes ($500 each)	500[1]	1 000[2]	1 000[2]***
• Ramp Signs			
— "Stop Here On Red"	400	400	400
— Advance Warning	400	400	400
— Advance Warning with Beacons	2 500	2 500	2 500

Notes:

* For an integrated freeway management system, costs can be assigned to the surveillance detectors on the mainline of the freeway and to the communications systems. Costs are for one ramp location.

** For one signal pole, with double heads located on left side of ramp, the cost for the single signal pole and foundation would be $1 500.

*** Does not include cost of communications, conduit, and pullboxes on the freeway mainline connecting the ramps.

Exhibit 8i

APPLICATION CRITERIA FOR RAMP METERING TECHNIQUES

APPLICATION CRITERIA	ALTERNATIVE TECHNIQUES		
	Fixed Time	Traffic Responsive	System Responsive
System Configuration			
• Single ramp	✓		✓
• Several individual ramps at long distances apart	✓	✓	
• Several closely spaced ramps	✓	✓	✓
• Numerous ramps	✓	✓	✓
Metering Rates			
• Based on time of day, day of week, historical data	✓	✓	✓
• Responsive to varying traffic flow		✓	✓
• Responsive to non-recurrent congestion (accidents, road maintenance, etc.)		✓	✓
System Operation			
• Accommodates single vehicle entry	✓	✓	✓
• Accommodates platoon entry	✓	✓	✓

9.
HOV PREFERENTIAL FACILITIES

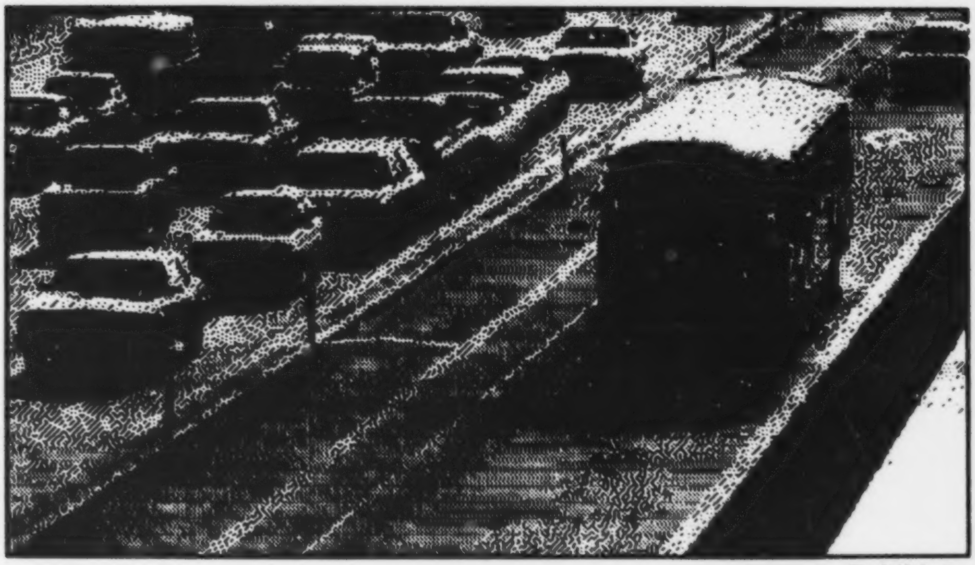


Exhibit 9a

9.1 Concept

High Occupancy Vehicle (HOV) Systems are based on providing preferential or exclusive treatment to vehicles containing several occupants. The objective in implementing such treatments is to optimize the person throughput capability of road facilities as opposed to the more conventional and limited approach of simply maximizing the vehicle throughput. Also, in calculating the 'throughput' for HOV systems, major parallel facilities in a corridor are usually included (as opposed to considering only a freeway, for example).

This approach represents a fundamental change in traffic management philosophy. High occupancy vehicles (HOVs) are considered to deserve better access to and from cities during peak periods on the basis of the social, economic and transportation rationale that each HOV only takes up one "slot" in the traffic stream (to transport several people) while a single occupant vehicle (SOV) demands the allocation of an exclusive "slot" for only one person.

This rationale is considered so strong, by those implementing HOV preferential treatments, that a significant travel time advantage (i.e. higher speed) is justified in favour of HOVs over SOVs. This travel time saving is aimed at encouraging the formation of additional car, van and bus pools as well as increasing the use of public transit. (Exhibit 9a).

The major techniques of providing preferential and exclusive treatment for high occupancy vehicles are:

- construction of exclusive HOV road facilities;
- designation of existing freeway lane(s) as exclusive HOV lane(s);
- designation or construction of HOV preferential or exclusive ramps;
- designation or construction of HOV preferential parking; and
- establishment of traffic signal preference or pre-emption system for buses.

9.2
Techniques

Exclusive HOV Road Facilities

There are three main techniques for providing exclusive HOV road facilities (possible configurations are presented in Exhibits 9b & 9c):

- construction of a freeway exclusively designated for use by HOVs during the peak periods;
- construction of a bus way — for example, a two lane parkway exclusively reserved for buses and possibly other HOVs, that may include van and carpools, and shared-ride taxis; and
- construction of reversible exclusive lanes in the median of an existing freeway.

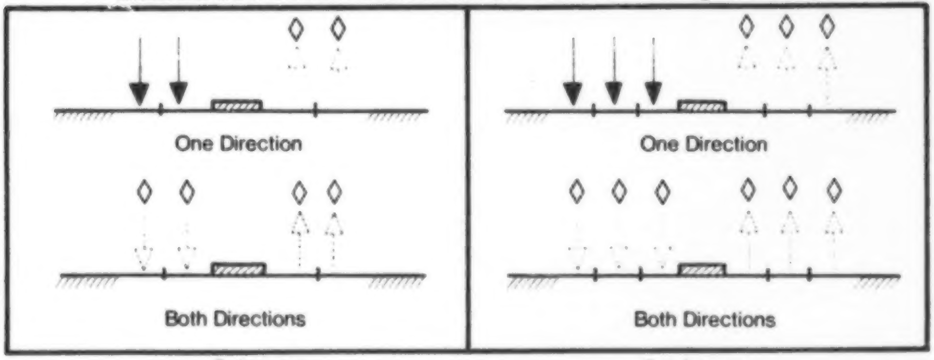
It should be noted that the construction of a new roadway facility is costly in terms of both money and the indirect energy used. Also, a new roadway facility will incur costs for subsequent maintenance in terms of both money and the direct and indirect energies used. However, these initial capital costs and the maintenance costs, can often be recouped through the accumulative annual savings in vehicle operating costs in both dollars and fuel. Indeed, this is always the case where the alternative would have been to provide even more extensive facilities for the use of all vehicles (usually resulting in the proliferation of travel by SOVs). In some locations, the initial costs can be reduced by constructing the facility on an existing rail or hydro right-of-way (for advantages/disadvantages, see Exhibit 9d).

Designation of Existing Freeway Lanes

There are two basic options to designate existing freeway lanes as exclusive HOV lanes:

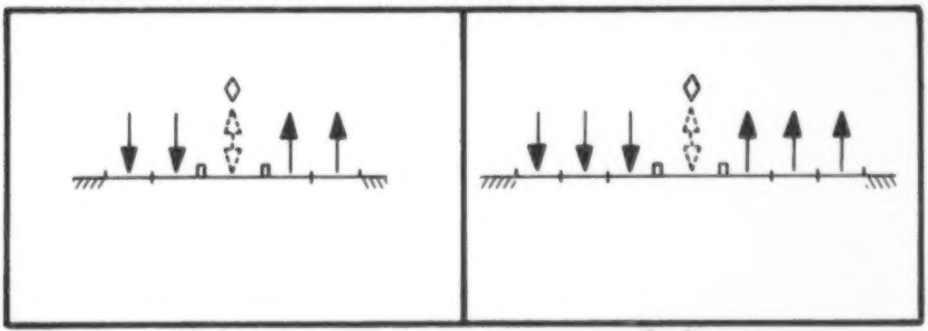
- concurrent flow (with flow), which pre-empts a travel lane from the peak direction. (Exhibits 9e-i); and
- contra-flow, which pre-empts the centremost lane from the off-peak direction. (Exhibits 9j-n).

Exhibit 9b
EXCLUSIVE HOV ROADWAY Possible Configurations



4 Lanes 6+ Lanes

Exhibit 9c
EXCLUSIVE HOV MEDIAN FACILITY Possible Configurations



5 Lanes 6+ Lanes

Exhibit 9d

ADVANTAGES AND DISADVANTAGES
OF
EXCLUSIVE HOV ROADWAYS

Advantages

- No reduction in efficiency of existing freeways
- Higher and more even operating speeds
- Reduced overall travel time
- Increased passenger throughput
- Safer operation by separating HOVs from other vehicles
- Effective and easier police enforcement
- Longer service lives
- Lower vehicle operating costs

Disadvantages

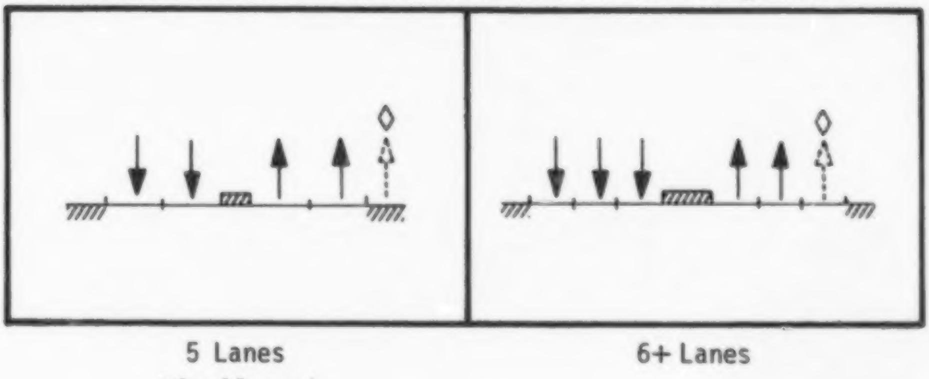
- High capital costs
- Additional maintenance costs
- Significant time frame to plan, design and implement
- Used only infrequently during off-peak periods.

In the concurrent flow situation, a separation from the regular traffic is provided by pavement markings (a minimum of 30 cm reflective cross hatching is desirable), and by the use of overhead variable message signs. Either the centremost lane or the right hand lane is used as the HOV lane. The designation of such lanes must always be supported by a timely public marketing program and by systematic enforcement with the application of sufficient fines for violations.

A contra-flow lane is selected when the directional traffic flows during peak hours are not in balance and when the facility does not have a sufficient number of lanes in each direction to designate a concurrent flow lane. This technique has the distinct advantage that it does not penalize any drivers in the predominant flow direction while still establishing a travel time advantage for the HOVs. Specific safety considerations should be addressed in order to minimize the potential for accidents. Furthermore, the cost of placing and removing traffic separation cones (where considered necessary) should also be considered.

Exhibit 9e

CONCURRENT FLOW RIGHT LANE Possible Configurations



5 Lanes
(shoulder use)

6+ Lanes

Exhibit 9f
CONCURRENT FLOW RIGHT LANE Signing and Marking

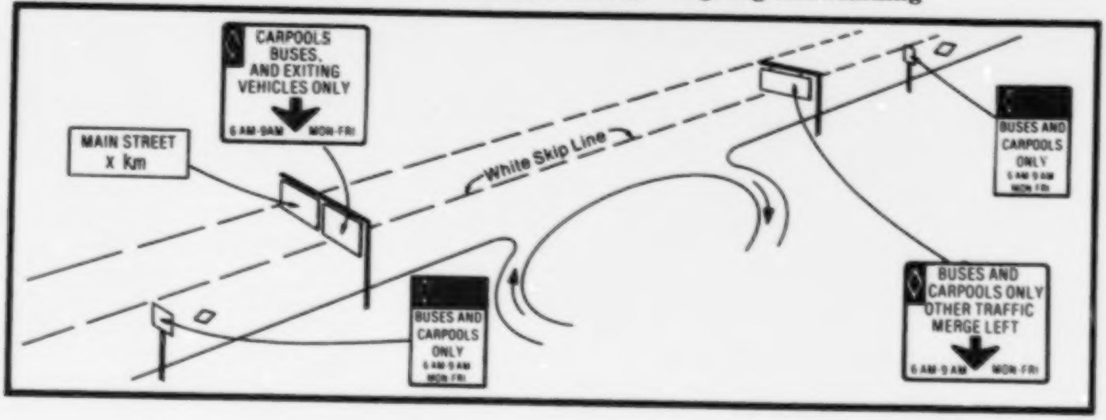
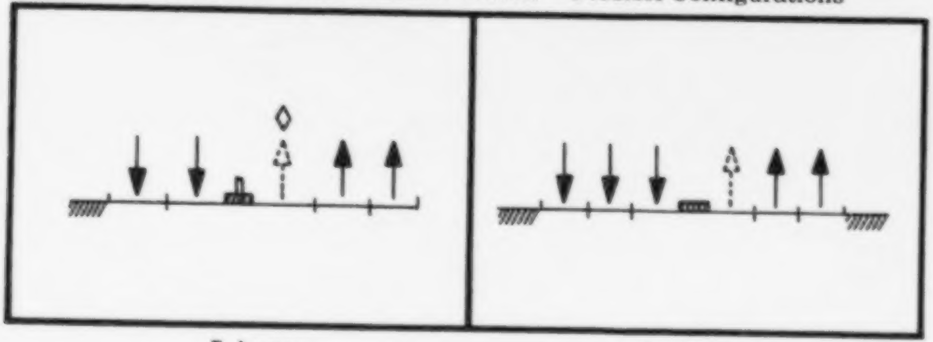

CARPOOLS
BUSES,
AND EXITING
VEHICLES ONLY
6 AM-9AM
MON-FRI
MAIN STREET
x km
White Skip Line
BUSES AND
CARPOOLS
ONLY
6 AM-9 AM
MON-FRI
BUSES AND
CARPOOLS ONLY
OTHER TRAFFIC
MERGE LEFT
6 AM-9 AM
MON-FRI
BUSES AND
CARPOOLS
ONLY
6 AM-9 AM
MON-FRI

Exhibit 9g
CONCURRENT FLOW LEFT LANE Possible Configurations



5 Lanes

6+ Lanes

Exhibit 9h
CONCURRENT FLOW LEFT LANE Signing and Marking

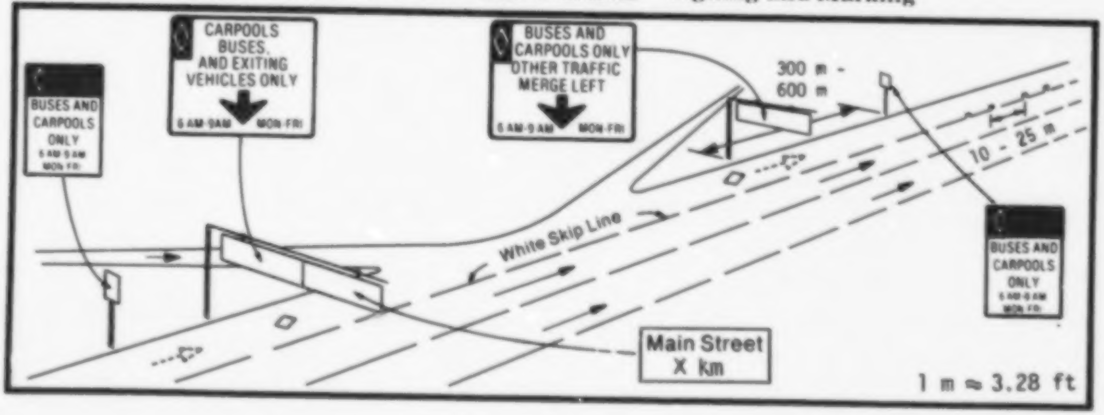

BUSES AND
CARPOOLS
ONLY
6 AM-9 AM
MON-FRI
CARPOOLS
BUSES,
AND EXITING
VEHICLES ONLY
6 AM-9AM
MON-FRI
BUSES AND
CARPOOLS ONLY
OTHER TRAFFIC
MERGE LEFT
6 AM-9 AM
MON-FRI
300 m -
600 m
10 - 25 m
White Skip Line
BUSES AND
CARPOOLS
ONLY
6 AM-9 AM
MON-FRI
Main Street
X km
1 m ≈ 3.28 ft

Exhibit 9i

ADVANTAGES AND DISADVANTAGES OF CONCURRENT FLOW LANES

Advantages

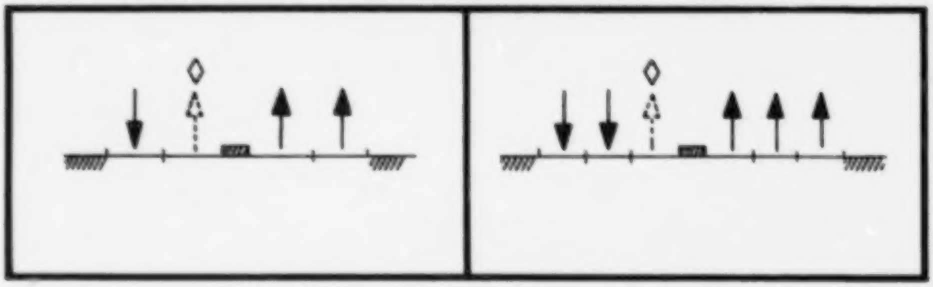
- A relatively low initial capital cost
- Easily implemented (from a physical standpoint)
- Increased person throughput
- Reduced travel time for HOVs
- Reduced HOV operating costs
- Value of ride sharing and transit emphasized (through some additional congestion on SOV lanes)
- Reduced proliferation of SOV travel
- Available for *all* vehicles during off-peak (and in off peak direction)

Disadvantages

- Reduced efficiency of the other travel lanes (until SOV travel time adjustments, and sufficient shift to HOVs)
- Single occupant vehicles penalized
- Difficulty in enforcement: violator assembly areas or change in moving violation regulations required
- A particularly timely implementation of an effective marketing and follow-up program difficult

Exhibit 9j

CONTRA FLOW INSIDE LANE Possible Configurations



4 Lanes

6+ Lanes

Exhibit 9k

CONTRA FLOW INSIDE LANE Signing and Marking

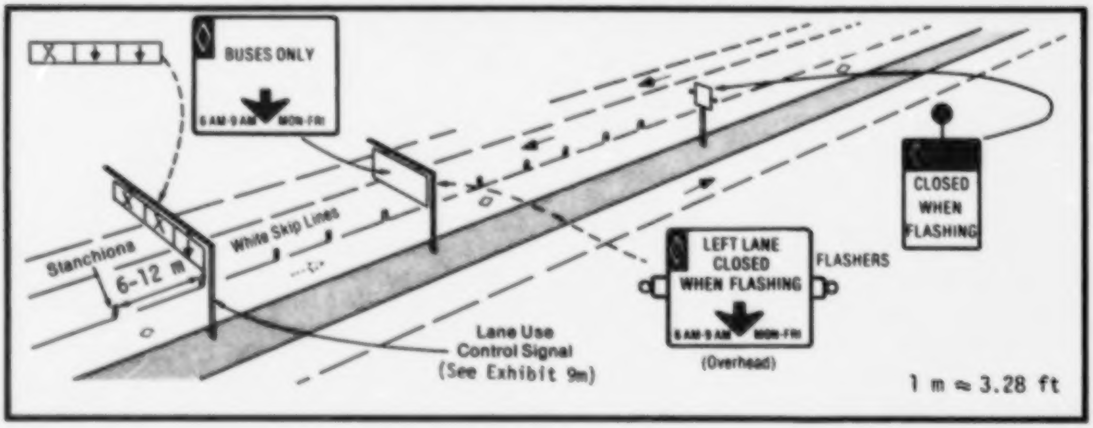

BUSES ONLY
6 AM-9 AM
MON-FRI
Stanchions
6-12 m
White Skip Lines
Lane Use Control Signal (See Exhibit 9m)
LEFT LANE CLOSED WHEN FLASHING
6 AM-9 AM
MON-FRI
(Overhead)
FLASHERS
CLOSED WHEN FLASHING
1 m ≈ 3.28 ft

Exhibit 9l

DESIRABLE CONTRA-FLOW DESIGN

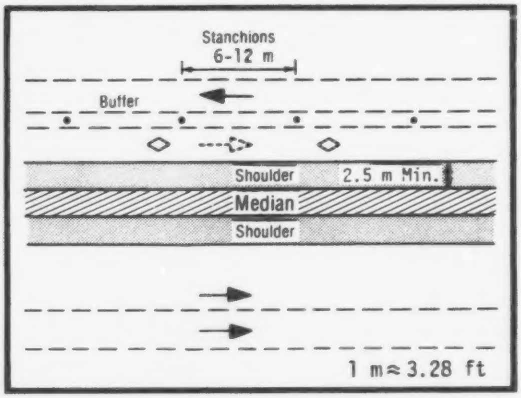


Exhibit 9m

CONTRA FLOW INSIDE LANE

Lane Use Control Signals

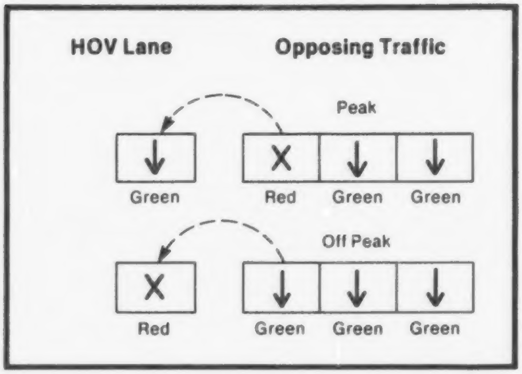


Exhibit 9n

ADVANTAGES AND DISADVANTAGES OF CONTRA-FLOW LANES

Advantages

- Enhanced passenger throughput
- Increased overall capacity in peak flow direction (by utilizing unused capacity in off-peak direction)
- A relatively low initial capital cost
- Usually readily implementable (from a physical standpoint)
- Reduced travel times, and operating costs, for HOVs

Disadvantages

- Possible congestion in off-peak direction (due to the occurrence of a capacity restricting incident)
- High day-to-day operating costs
- Possibility of high speed head-on collisions
- Modifications to the median of the highway required
- May be considered unsafe for van and carpools (without special training and an exam)
- Special procedures for handling of incidents required.

Preferential Ramps

Preferential treatment of car/van/bus pools and conventional transit can be applied at both entrance ramps and exit ramps of a freeway, particularly during the a.m. and p.m. peak periods. The two major types of preferential treatment are (Exhibits 9o-s):

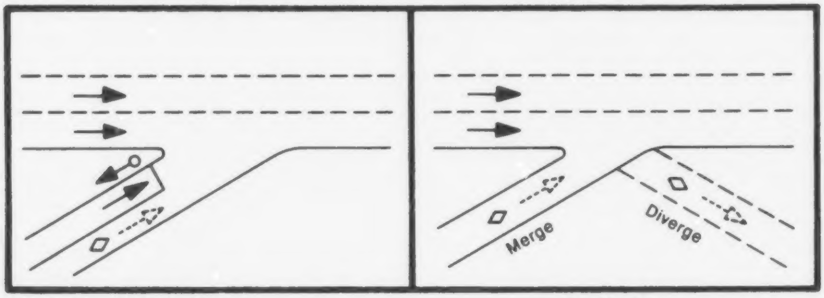
- priority entry whereby a by-pass lane is implemented at ramp metering locations so that the HOVs can by-pass the control queues of single occupancy vehicles without stopping.
- exclusive HOV exit and/or entry ramp in the central city area.

In many locations, where sufficient pavement widths exist, the HOV by-pass lanes can be indicated simply by pavement markings. In the event where sufficient pavement widths are not available, a physical widening of the ramp or construction of an entirely separate entry ramp will be required to minimize the effect of the queueing of single occupant vehicles that are awaiting entry to the freeway at a ramp metering location. A similar application is the establishment of a special reserve lane at a toll booth for high occupancy vehicles. Such a reserve lane permits high occupancy vehicles to by-pass the vehicles queued at other toll booth lanes. Some reserved HOV lane applications include the use of automatic vehicle identification (AVI) equipment — so that the bus company is automatically billed without the bus having to stop to pay the toll.

In the central city area, it is possible to establish exclusive HOV ramps. In the a.m. peak hours certain exit ramps can be designated for exclusive use by HOVs. This approach would permit increases in the total number of persons permitted entry to, or exit from, the freeway facility.

Exhibit 9o

RAMP TREATMENTS Possible Configurations


Merge
Diverge

Ramp Meter Bypass

Exclusive HOV Ramp

Exhibit 9p

METERED RAMP BYPASS DESIGNS

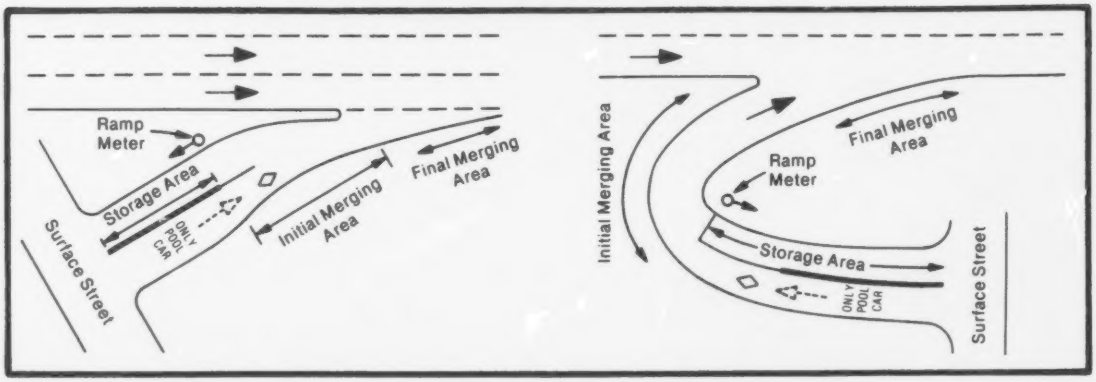

Ramp Meter
Storage Area
ONLY POOL CAR
Initial Merging Area
Final Merging Area
Surface Street
Initial Merging Area
Ramp Meter
Final Merging Area
Storage Area
ONLY POOL CAR
Surface Street

Exhibit 9q

EXCLUSIVE RAMP DESIGNS

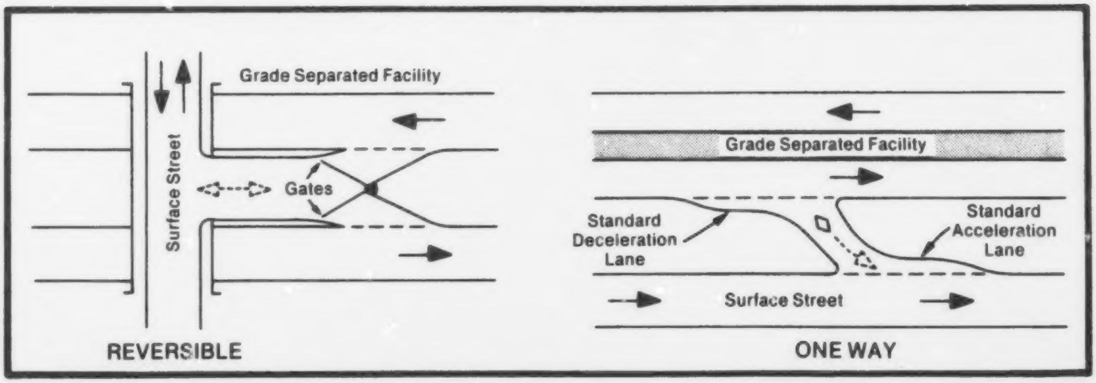

Grade Separated Facility
Surface Street
Gates
REVERSIBLE
Grade Separated Facility
Standard Deceleration Lane
Standard Acceleration Lane
Surface Street
ONE WAY

Exhibit 9r

RAMP TREATMENTS Signing and Marking

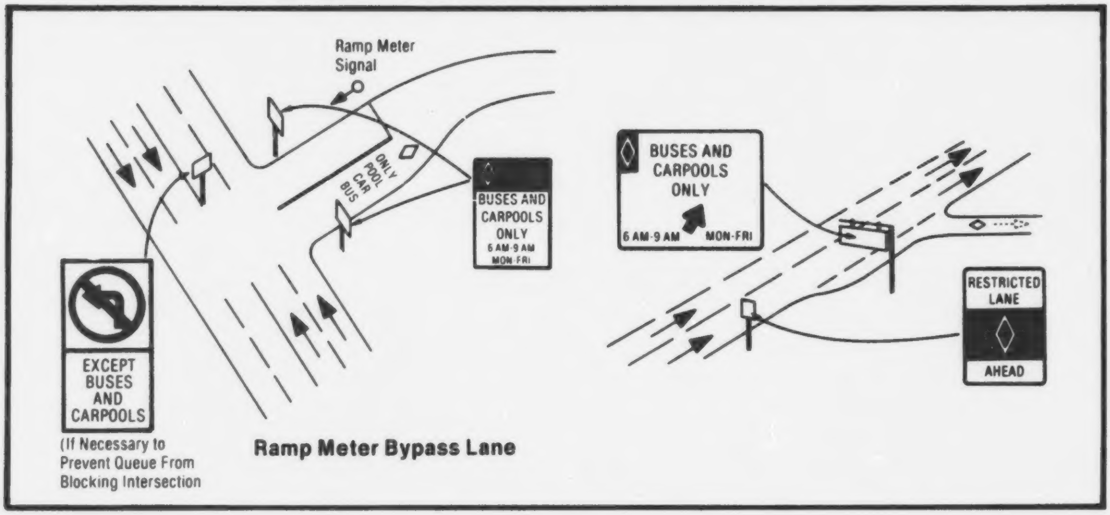

Ramp Meter Signal
ONLY POOL CAR BUS
BUSES AND CARPOOLS ONLY 6 AM-9 AM MON-FRI
BUSES AND CARPOOLS ONLY 6 AM-9 AM MON-FRI
RESTRICTED LANE AHEAD
EXCEPT BUSES AND CARPOOLS
(If Necessary to Prevent Queue From Blocking Intersection
Ramp Meter Bypass Lane

Exhibit 9s

ADVANTAGES AND DISADVANTAGES OF PREFERENTIAL AND EXCLUSIVE HOV RAMPS

Advantages

- Increased throughput of people in high occupancy vehicles
- Overall (person) travel time savings
- Clear, visible preference for HOVs over SOVs: modal shift to ridesharing over time
- Easier police enforcement: low speeds permit violators to be readily identified
- Low capital as well as operating costs

Disadvantages

- HOVs will not avoid congestion on the general mainline of the freeway (unless enough ramps designated, or an HOV 'package' implemented)
- Increased travel times for SOVs
- Possibly difficult to construct a by-pass lane on a ramp in urban areas: due to adjacent roadways, retaining walls or buildings
- Spillover congestion on approach arterials (due to additional SOV line-ups).

Preferential Parking

The implementation of preferential parking for HOVs can play an important role in an overall "package" of HOV treatments — by complementing other measures which can be implemented within a typical freeway corridor management system. There are two basic approaches:

- construct unsupervised peripheral parking lots adjacent to major freeway interchanges at arterial intersections along high demand commuter corridors at the metropolitan fringes (Exhibits t-u);
- designate one or more, usually municipally controlled parking facilities located near the highest concentration(s) of employment within a CBD as exclusive HOV facilities whereby the entry of SOVs would be prohibited at least during the morning peak hours and the 'shoulder' periods, e.g. from 6:00 a.m. to 10:00 a.m. For advantages/disadvantages see Exhibit 9v.

Exhibit 9t

PARK AND RIDE LOCATIONS

Perimeter of a Congestion Zone

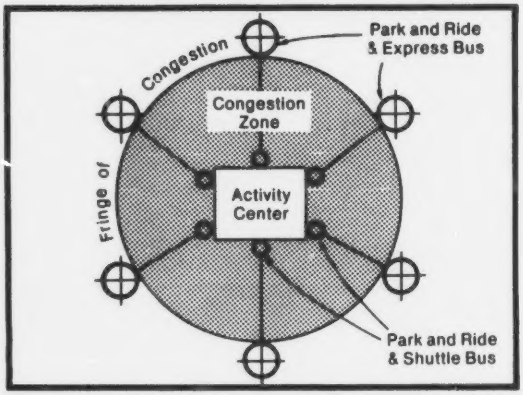

Park and Ride & Express Bus
Fringe of Congestion
Congestion Zone
Activity Center
Park and Ride & Shuttle Bus

Exhibit 9u

PARK AND RIDE LOCATIONS Freeway Interchange

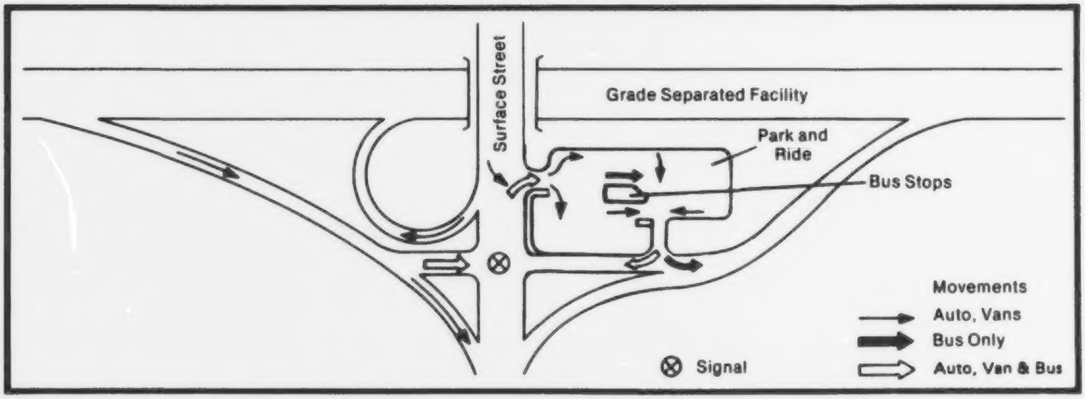

Surface Street
Grade Separated Facility
Park and Ride
Bus Stops
Movements
Auto, Vans
Bus Only
Auto, Van & Bus
⊗ Signal

Exhibit 9v

ADVANTAGES AND DISADVANTAGES OF PREFERENTIAL AND EXCLUSIVE HOV PARKING

Advantages

- Very low capital cost, and only a small increase in operating costs (i.e. for enforcement), when designating existing parking facilities in CBD
- Reduction in the growth of overall peak hour vehicle demands — due to shift from SOVs to HOVs
- Increased person throughput in both freeway and some arterial corridors
- Fringe sites also useful as carpool assembly areas for outbound intercity day trips
- Increased attractiveness of conventional transit — due to increased walking distances from SOV parking sites

Disadvantages

- Costly, where acquisition of prime commercial property required
- Some capital and annual maintenance costs for typical metropolitan fringe sites
- Cost of periodic patrols to minimize vandalism and theft of parked vehicles (some fringe sites)
- Difficult parking revenue balancing in major CBD applications (i.e. setting of parking rates and definition of pools)

Traffic Signal Pre-emption

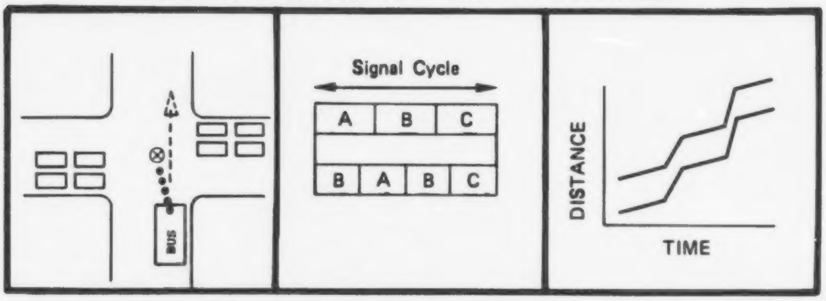
A signal pre-emption is made possible by installing special sending units, or pre-emption equipment, in the transit vehicles (buses and streetcars) and corresponding receiving units in the selected signal control boxes. These allow the drivers to request for green signals, or extensions of the green time, so that stopped time at those signals can be reduced (Exhibits 9w & 9x).

The city of Edmonton has used a pre-empt signal for buses which is *not* green — to avoid confusing other vehicles. This approach is presently being documented by Project Committee #120 of the Council on Uniform Traffic Control Devices.

In a freeway corridor management system, the signals are selected to facilitate easier access to the preferential ramps and lanes of the freeway from the adjacent arterial facilities. The use of traffic signal pre-emption system is generally limited to locations within or adjacent to CBD's where heavy traffic volumes already exist on the signalized arterial network.

Exhibit 9w

SIGNAL PRIORITY Possible Situations



Signal Preemption Phasing Adjustments Offset Adjustments

Exhibit 9x

ADVANTAGES AND DISADVANTAGES OF TRAFFIC SIGNAL PRE-EMPTION SYSTEMS

Advantages

- Reduction in stops and delays of transit vehicles
- Increased person throughput at the selected intersections
- Lower transit vehicle operating costs
- Quicker access for buses between the freeway and the adjacent arterial network

Disadvantages

- Some impedance to crossing automobile traffic
- Increased complexity in a coordinated traffic signal system: possible decrease in overall (vehicle) throughput efficiency
- Costly for many low volume sites on the metropolitan fringe

9.3 Equipment

The primary elements of the various HOV preferential techniques are presented in Exhibit 9y.

Exhibit 9y
HOV PREFERENTIAL FACILITY EQUIPMENT

HOV TECHNIQUE	EQUIPMENT
Exclusive HOV Roadways	• Construction materials for road bed and pavement • Signs and control equipment • Pavement markings • Auxiliary road devices (such as guide rail, median barrier, . . .)
Designation of Existing Freeway Lanes	
a. Concurrent Flow	• Pavement markings and advisory signs • Changeable message signs and control equipment • Violator assembly sites
b. Contraflow Lane	• Crossover facility onto the off-peak side • Traffic cones and placement cylinders in pavement • Pavement markings and advisory signs • Changeable message signs and control equipment • Vehicles to be utilized for installation and removal of the cones • Training facility for van and car pool drivers
HOV Preferential Ramps	
a. Priority Entry By-Pass Lanes (Sufficient Pavement Widths)	• Pavement markings • Signs and control equipment
b. Priority Entry By-Pass Lanes (Construction of Additional Pavement)	• Construction materials for widening of ramp(s) • Pavement markings and advisory signs • Changeable message signs and control equipment
c. Designation of Exclusive HOV Ramps	• Pavement markings and advisory signs • Changeable message signs and control equipment
Preferential & Exclusive Parking	
a. Existing Lots & Garages	• Advisory signs
b. Construction of New Facilities	• Construction materials for parking lot or garage • Advisory signs • Pavement Markings
Traffic Signal Pre-emption System	• Pre-emption sending units on transit vehicles • Traffic signal pre-emption receiver • Interface equipment in traffic control field cabinet

9.4 Cost Components

Approximate cost for the main techniques of providing preferential treatment to high occupancy vehicles (HOVs) are presented in Exhibit 9z.

9.5 Application Criteria

The selection of an HOV treatment for implementation at any given site will depend heavily on the specific roadway configuration as well as on the current travel demand situation. A preliminary indication of whether the specific techniques might be applicable in various roadway and operating situations is given in Exhibit 9zz. It should be noted that this exhibit is intended to serve only as a guideline that should be used along with the application of good engineering judgment for each particular location.

Note about exhibits within Chapter 9:
Exhibits 9b, c, e, f, g, h, j, k, l, m, n, o, p, q, r, t, u and w were reproduced from "High Occupancy Vehicle Facility Development—Operation and Enforcement" by J.H.K. & Associates for FHWA/U.S. DOT, April 1982.

Exhibit 9z
APPROXIMATE COSTS FOR HOV PREFERENTIAL TREATMENTS

COMPONENT	COSTS ($)
Exclusive HOV Facility	1.5M - 3M per km
Concurrent Flow Lane	2 300 - 8 000 per km
Contra Flow Lane(1	3 000 - 170 000 per km
HOV By-Pass Lane(1	3 000 - 50 000 per ramp
Preferential Parking Facility(2	1 000 - 2 000 per space
Traffic Signal Pre-Emption System	
— Intersection Control Modifications	3 000 per intersection
— Equipment on Bus	1 500 per bus

Note:

1) Lower costs ($3 000) include only the striping of one lane. Higher costs ($170 000 & $50 000) include striping, variable message signs and daily installation & removal of cones.
2) Existing lots can often be leased for nominal monthly costs (e.g. a church lot, or portion of a shopping centre lot).

Exhibit 9zz
APPLICATION CRITERIA FOR HOV PREFERENTIAL TREATMENTS

	ALTERNATIVE HOV TECHNIQUE							
	EXCLUSIVE HOV LANES		CONCURRENT FLOW LANES		CONTRA FLOW LANES	PREFERENTIAL RAMP TREATMENTS	PREFERENTIAL PARKING	TRAFFIC SIGNAL PRE-EMPTION
APPLICATION CRITERIA	Separate Facility Roadway	Reversible Lane in Median	Right Lane	Inside Lane	Inside Lane			
Configuration								
• Separate roadway	✓							
• Sufficient median width		✓						
• Lane from opposite flow direction					✓			
• Lane from same direction			✓	✓				
• Ramp revisions			✓			✓		
Design Effort	Minimum	Extensive	Moderate	Minimum	Moderate	Moderate	Moderate	Minimum
Effectiveness	High	High	Low	Medium	High	Medium	Medium	Medium
• Increased passenger throughput	✓	✓	✓	✓	✓	✓		✓
Traffic Operations	Good	Good	Fair	Fair	Fair	Good	Good	Good
• Express bus service	✓	✓	✓	✓				✓
• Local bus service without turnouts								✓
• Local bus service with turnouts		✓	✓					✓
• Reduced capacity of Freeway			✓	✓				
• Possibility of high speed head-on collisions					✓			
Enforcement	Minimal	Minimal	Difficult	Difficult	Minimal	Minimal	Minimal	Minimal
Cost	Medium	High	Low	Low	Medium	Low	Low	Low
Public Reaction (by SOV drivers)								
• Adverse			✓	✓				
• Popular	✓	✓			✓		✓	✓

10.
DRIVER INFORMATION SIGNING

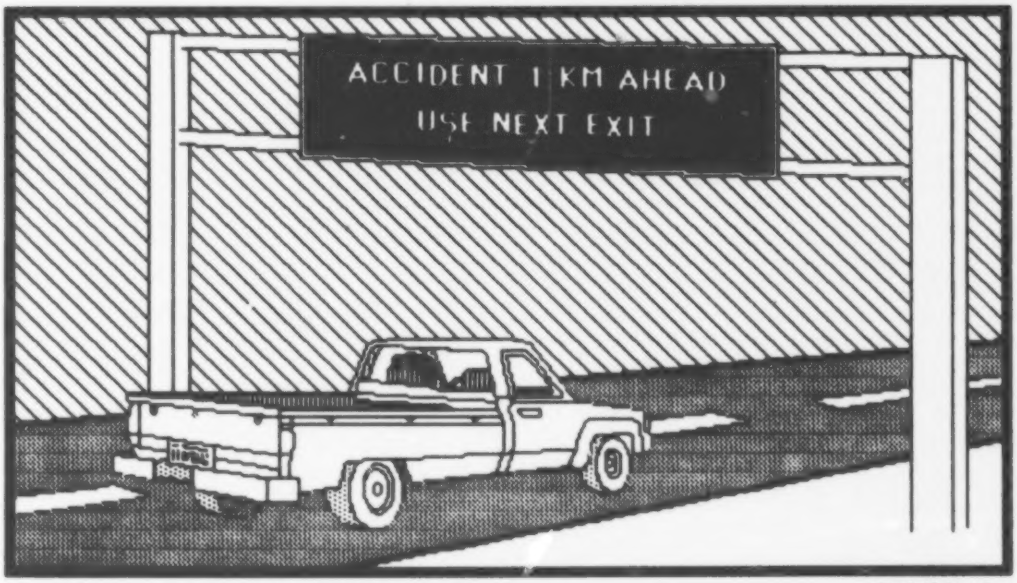


Exhibit 10a

10.1 Concept

When a motorist is caught in a traffic jam, his/her primary concerns and questions are:

- What has caused the traffic jam and where is the incident located?
- How long will I remain in the traffic jam?
- Where am I, and are there any good alternative routes around the traffic jam?
- Are traffic conditions any better on the alternative routes?
- Why could I have not been forwarned about the traffic jam *prior* to entering this roadway section (so that I could have considered taking an alternative route in the first place)?

Driver information sign systems are aimed at communicating to the motorist specific information about the traffic conditions, so that the uncertainty and aggravation about travel times can be minimized and each trip can be made as safe as possible. The information is provided to the motorist via fixed or variable message signs — or via highway advisory radio systems, which are described in Chapter 11 of this guidebook.

In order for the motorist to have confidence in the information provided, it is essential that it be as up-to-date and accurate as at all possible. The effectiveness of applying driver information techniques as part of an overall freeway management system, is heavily dependent on gaining and retaining the confidence of the motorists.

Purposes

The main purposes for which communications with the motorists are required for driver information systems include:

1) Traffic Management and Diversion
    - Freeway traffic advisory and incident management
    - Special event advisory
    - Speed control
2) Warning of Adverse Conditions
    - Weather and environmental conditions
    - Road conditions
3) Control During Construction and Maintenance
    - Warning
    - Speed control
    - Route and lane control

4) Special Useage Lanes of Roadway Control
- Reversible lanes
- Exclusive lanes
- Restricted lanes

Traffic Diversion and Alternative Routing Systems

When stuck in a traffic jam, a motorist will often wonder whether there are any alternative routes around it. In cases where an alternative route closely parallels the freeway, the motorist can actually look over to the parallel facility and often see that traffic is moving freely, or at least much better, while he/she is stuck in the traffic jam. For most, this can be a cause of serious frustration.

Traffic diversion and alternative routing systems are aimed at:

- balancing the (normal) peak travel demands to better match the available throughput capacities of all parallel facilities in a commuter corridor;
- minimizing the overall (corridor) delays in the case of an incident on the freeway;
- minimizing the overall (corridor) delays in the case of construction or maintenance activity on the freeway; and
- in each instance, reducing the aggravation of the motorists.

Once an incident detection system has been established on the freeway and the alternative routes, it is possible to transform a driver information system of variable message signs and highway advisory radio into a full traffic diversion and alternative routing system. Messages can then be displayed and transmitted via radio — to advise motorists of the best routes to reach particular destinations or to bypass an incident or traffic congestion.

It should be emphasized that the success of a traffic diversion and alternative routing system is dependent upon the alternative routes possessing an incident detection system. Only then can the traffic conditions on the alternative routes be properly monitored — to assure that these facilities can, in fact, accommodate the diverted traffic without the conditions becoming worse than exist on the main roadway.

The major types of traffic diversion and alternative routing systems are briefly described in the following:

Single Point Diversion — In a single point diversion system, there is a divide or interchange in the roadway where motorists can either continue straight ahead or divert to an alternative route — to reach a common end point (where the roadways connect again). One example of such a system is where a highway runs through a city, while another roadway separates from or interchanges with the main highway and then travels around the outside of the city area to again join or interchange with the highway on the other side of the city. Another example of a single point diversion system is where a freeway is entering a city that has several bridge crossings; thus, a motorist desiring to head to a destination on the other side of the river could exit the freeway at an interchange and utilize the first bridge to reach a local street or could continue to the next exit to utilize the farther bridge to connect to the same local street. Thus, there is one single point where the motorist can divert from the freeway and still reach a common destination point within the city.

In a single point diversion system, signs can be located upstream from the diversion point with messages displayed about the traffic conditions on the two alternative routes so that the driver can choose the least congested route to the common destination point.

Freeway to Freeway Diversion — In some major transportation corridors, there can be two freeways running almost parallel to each other, or crossing each other at several points. In these situations, it is possible to establish a freeway corridor management system in which motorists are diverted from one freeway to another — in order that they may avoid a particularly congested section or an incident site. Variable message signs are again installed upstream from (each of) the diversion points to display information on traffic conditions so that the route having the best traffic conditions can be selected by the motorist. In the case of freeway-to-freeway diversion, the motorist would leave one freeway via a direct interchange connector to enter onto the adjacent freeway without utilizing local roadways.

Freeway to Arterial Diversion — In freeway management systems where there is an arterial roadway running adjacent to or crossing a freeway, it is possible to divert motorists around traffic incidents and congestion by advising them of the alternative arterial roadways and the traffic conditions on them. Before encouraging motorists to divert to the local arterials, the conditions on these roadways should be examined based on information obtained from their surveillance systems. Furthermore, if the arterial roadways have signalized intersections, it is essential that the signal system has the flexibility to change and accommodate the diverted traffic without creating undue congestion. Indeed, the accuracy and reliability of the traffic diversion and alternative routing system information must be maintained at all times — to retain the confidence and support of the motorists.

The configuration of a freeway management system may also permit freeway to arterial to freeway diversion. In other words, the motorist could depart from one freeway to an arterial roadway to travel past the incident or traffic congested location and re-enter the same freeway or an adjacent freeway downstream of the incident.

Information on major types of variable message signs used in driver information signing systems is presented in the following.

10.2
Techniques

Variable message signs can be either small single message signs, or larger signs which can display a number of messages — much like scoreboard displays at sports stadiums. Depending on the type and design of the variable message sign:

a) a certain number of predetermined messages can be included in the software program of the system; or
b) an unlimited number of messages can be provided by entering each message directly through a keyboard in the control centre.

The primary factors to be considered in selecting the variable message sign type are:

- The intended features and size of the overall freeway management system;
- Ability to accommodate large message complements;
- Flexibility to change messages or incorporate new messages without hardware modifications;
- Proven operational capability of the make/type of the sign; and
- Capital, maintenance and operating costs

The different types of variable message sign which are suitable for outdoor use may be grouped according to external appearance into the following three categories:

- Roller-shade (scroll);
- Rotating drum;
- Matrix: lamp, disk, flap, fiber optic

Roller-Shade Signs (Scroll)

Roller-shade signs make use of a continuous belt upon which a series of messages is printed. The messages are contained on a plastic film that is stored and transported on two roller-type drums fastened horizontally to the sides of the sign (Exhibit 10b). However, only a limited number of messages can be used on a belt (typically, a maximum of twelve). No signs of this type are presently made large enough to accommodate the requirements of freeway diversion application (e.g. two or three lines with 38-46 cm character height).

The advantages and disadvantages of roller-shade signs are presented in Exhibit 10c.

Rotating Drum

Rotating drum signs are made up of one or more multifaced prisms (drums) upon which message panels are attached (Exhibit 10d).

Exhibit 10b
SCROLL SIGN LAYOUT — Side View

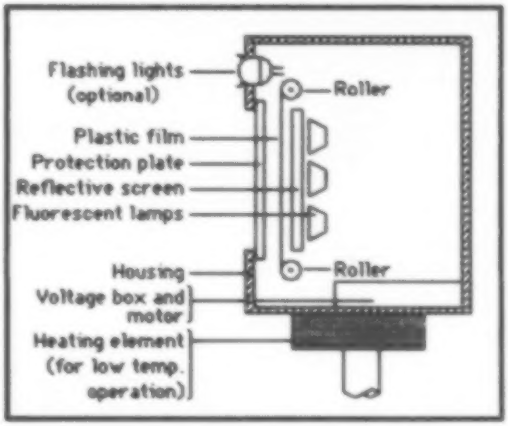
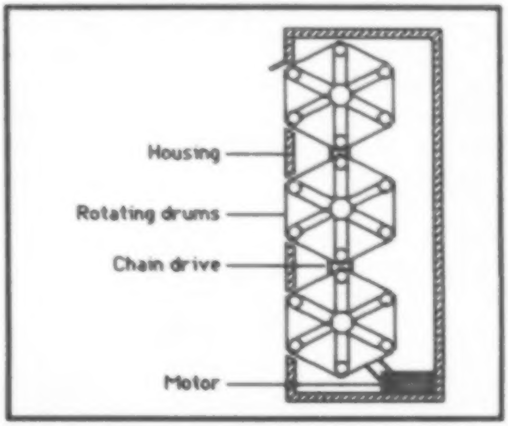


Exhibit 10d
DRUM SIGN LAYOUT — Side View



Most present drums have 3, 4 or 6 faces. Multi-line signs are produced by stacking a series of drums in a single enclosure.

The advantages and disadvantages of rotating drum signs are presented in Exhibit 10e.

Lamp Matrix Signs

The incandescent bulb matrix sign display consists of a number of modules (one module per character) by size, in a metal housing. Each module is typically a matrix of 35 bulbs (5 columns of 7 bulbs each), with appropriate bulbs illuminated to form an alphanumeric character. Horizontal louvered sun screens are sometimes used to improve readability and prevent phantom images caused by sunlight shining directly into the sign face (Exhibit 10f). Generally, the sign enclosures are sealed and waterproofed and some use a water drainage system. The bulb matrix sign has the potential for unlimited message capability. It is manufactured in sizes large enough for use on high-speed highways and has good readability under a wide range of ambient light conditions.

Exhibit 10c

ADVANTAGES AND DISADVANTAGES
OF
ROLLER-SHADE VARIABLE MESSAGE SIGNS

Advantages

- Simple operating principle
- Environmentally protected
- Stand-by power source included (some models)
- Mobile operation possible
- Conformance with highway signing standards
- Maximum character height of 61 cm

Disadvantages

- Limited number of fixed messages available (12 maximum)
- Periodic cleaning of sign required
- Time to change messages excessive: can cause driver confusion.
- Jamming of control console push button not uncommon
- Not large enough to accommodate freeway diversion applications (i.e. 2 or 3 lines with 38-46 cm character height).

Exhibit 10e

ADVANTAGES AND DISADVANTAGES
OF
ROTATING DRUM VARIABLE MESSAGE SIGNS

Advantages

- Simple to operate and maintain
- Conforming to manual of uniform traffic control devices
- Operable from a battery or a hand crank (in the event of a power failure)
- Good visibility

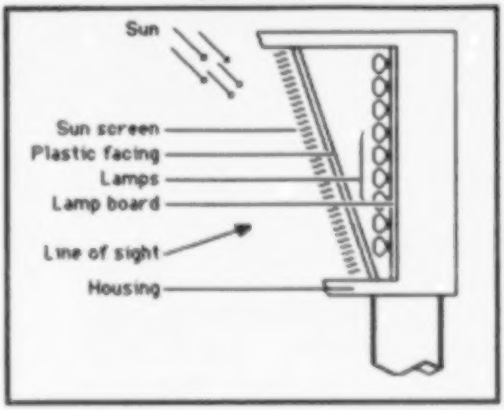
Disadvantages

- Not generally environmentally sealed
- Periodic cleaning required (due to the accumulation of dirt, dust and debris)
- Replacement of the entire fixed message panel required (to change a line of text copy on the sign)
- Periodic adjustments in the electro-mechanical cam required (to prevent a jam, a lock and misregistry)
- Size and number of faces on a drum limited (where larger characters required)
- Possible driver confusion due to slowness of changing messages (up to 30 seconds.)
- Limited number of messages.

Exhibit 10f

LAMP MATRIX SIGN LAYOUT

Side View


Sun
Sun screen
Plastic facing
Lamps
Lamp board
Line of sight
Housing

The advantages and disadvantages of lamp matrix signs are presented in Exhibit 10g.

Disk Matrix Signs

The disk matrix sign produces messages in the same manner as the bulb matrix sign, except that it uses disks in place of bulbs. The disks have the sign background colour on one side and a contrasting colour on the other. The disks are pivoted and flipped from one side to the other by electro-magnetic means (Exhibit 10h).

Their high reliability has been proven in outdoor advertising usage, where messages are changed up to four times a minute, continuously, throughout the day. Disk signs must be

Exhibit 10g

ADVANTAGES AND DISADVANTAGES OF LAMP MATRIX SIGNS

Advantages

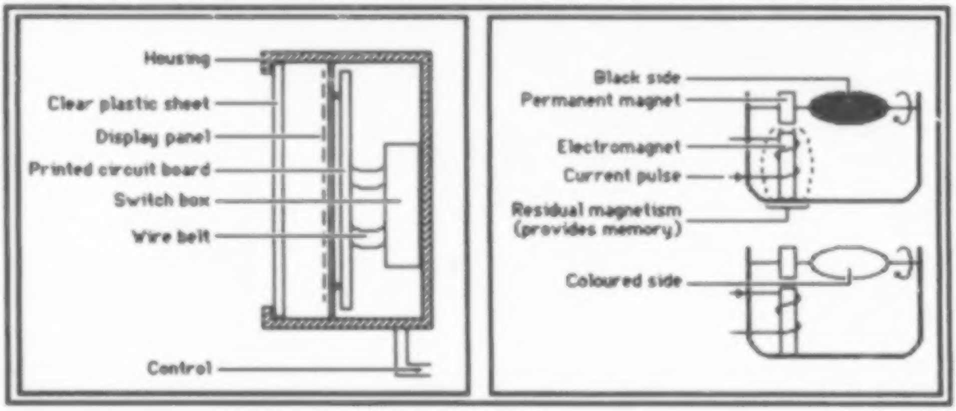
- High target value
- Several operating modes (instantaneous, writing and flashing)
- Total flexibility of the sign's copy
- Potential for unlimited message capability
- Manufactured in sizes large enough to use on high-speed highways
- Good readability in a wide range of ambient light conditions
- No separate illumination required at night

Disadvantages

- High maintenance costs
- High operating costs
- Continuous power required
- Many auxiliary control systems require trained personnel
- Confusing characters or messages (in the case of lamp failures)
- Bulb maintenance required

Exhibit 10h

ELECTROMAGNETIC DISK MATRIX SIGN Sign Layout and Disk Element


Housing
Clear plastic sheet
Display panel
Printed circuit board
Switch box
Wire belt
Control
Black side
Permanent magnet
Electromagnet
Current pulse
Residual magnetism
(provides memory)
Coloured side

externally illuminated for nighttime hours; however, only a modest amount of power (about 1 000 W) is required for this purpose. The major advantage is that once the disk is flipped, it remains stable in that position, thus virtually no power is needed to sustain a given message. A sealed enclosure provides environmental protection.

Present disk matrix signs "write" a message on a character-by-character, line-by-line basis. This type of writing can be considered somewhat of a disadvantage compared to the bulb matrix's instantaneous message change capability — particularly for a "flashing message" display. However, writing speeds for the disk signs are quite fast, normally less than one second per line so that this should not constitute a significant problem. The advantages and disadvantages of disk matrix signs are presented in Exhibit 10i.

Electrostatic Flap Matrix Sign

A relatively new type of matrix sign uses electrostatically positioned vanes to form the desired message. The vanes are moved into either of two positions: erased (hidden from view) or written (in view). The sign face is made up of modules, each containing a specified number of vanes (typically 100). The modules sit closely together horizontally and vertically, and thus characters may cross module boundaries and can be of any size or shape. From close range, the size face has a mosaic tile appearance (Exhibit 10j).

The display itself is passive; that is, it does not emit light but rather controls the passage and reflection of lights. Power consumption for vane operation is low but the signs do require illumination (usually internal) for low ambient light conditions. The sign enclosure is sealed for environmental protection. The sign maintenance requirements should be relatively small.

One disadvantage of the vane matrix sign is that it has a somewhat limited viewing angle, since the vanes extend outward (edge toward the viewer) in the erased position. Furthermore, the sign operates from a high-voltage source (typically thousands of volts) — and, therefore, requires a high-voltage enclosure to protect the electrostatic vane mechanism from the effects of moisture and dust. Since the electrostatic parts tend to attract dust, the enclosure must be carefully sealed.

Exhibit 10i

ADVANTAGES AND DISADVANTAGES OF DISK MATRIX SIGNS

Advantages

- Low power consumption
- Low maintenance costs
- High reliability
- Total message or display flexibility
- Good environmental protection
- Internally serviceable
- High contrast ratio and good message clarity under all light conditions
- Cannot be washed out by intense sunlight
- Only a modest amount of power (about 1 000 W) required for nighttime external lighting
- Stable in a particular position once a disk is flipped: requires virtually no power to sustain a given message

Disadvantages

- Trained technician required for servicing
- Heavier than most variable message sign displays (depending on model and manufacturer)
- Fluorescent or flood light front lighting required for nighttime operation
- Visual impact diminished on cloudy days and at twilight (depending on manufacturer)
- No secondary power source.

Perhaps the major disadvantage of the vane matrix sign is associated with its message-writing speed. Messages are written across the sign face from left to right. A present display containing 120 columns of vanes requires 30 seconds for the entire display to change. While the next generation of signs may be improved in this regard, at present this factor represents a serious drawback for application on freeways.

The advantages and disadvantages of electrostatic flap matrix signs are presented in Exhibit 10k.

Exhibit 10j

ELECTROSTATIC VANE MATRIX SIGN

Element and Control System Wiring Layouts

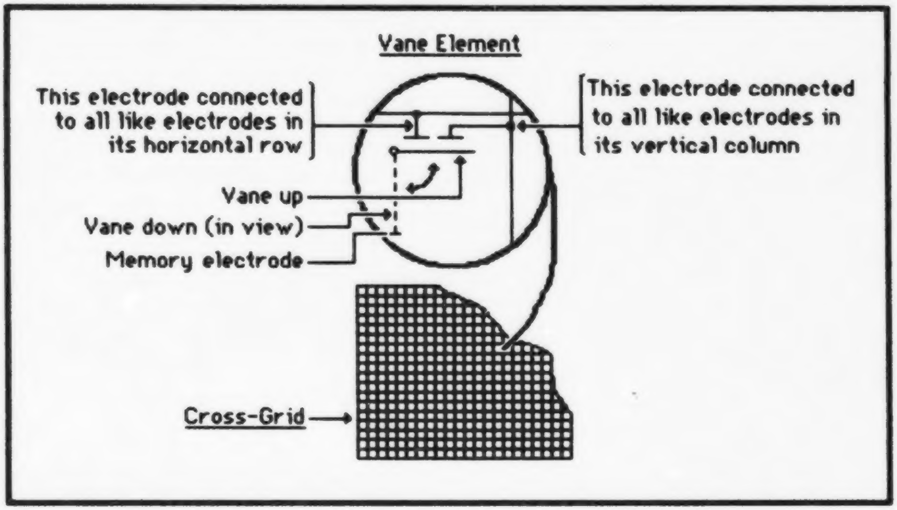

Vane Element
This electrode connected to all like electrodes in its horizontal row
This electrode connected to all like electrodes in its vertical column
Vane up
Vane down (in view)
Memory electrode
Cross-Grid

Exhibit 10k

ADVANTAGES AND DISADVANTAGES OF ELECTROSTATIC FLAP MATRIX SIGNS

Advantages

- Simple operating principles and control wiring
- No power semiconductor required
- Battery power as an option
- Total message flexibility: symbols, pictorials, and legends
- Totally portable
- Environmentally protected and sealed

Disadvantages

- Considerable amount of time required to change messages
- Trained technician required for servicing
- Restricted viewing angle: may reduce the covered zone on a roadway
- High-voltage enclosure required: to protect the electrostatic vane mechanism from the effects of moisture and dust

Fibre-Optic Sign
Another relatively new type of matrix sign uses fibre-optic light pipes to guide light from a single lamp to the matrix points that make up the selected legends. Each different legend is produced by switching to another lamp and a different set of pipes (Exhibit 10l).

The major advantages for this type of sign (compared to a full-bulb matrix sign) are lower maintenance and power consumption because fewer bulbs are used, and reduced phantom images and more readable characters due to the narrow light beam. A disadvantage is that the number of messages is limited and it is difficult to change or add new messages. The fibre-optic matrix sign technology is in a fairly early stage of operational use and is believed to have not yet been applied to large freeway-type signs.

The advantages and disadvantages of fibre-optic signs are presented in Exhibit 10m.

Exhibit 10 l

FIBRE-OPTIC MATRIX SIGN

Message Layout

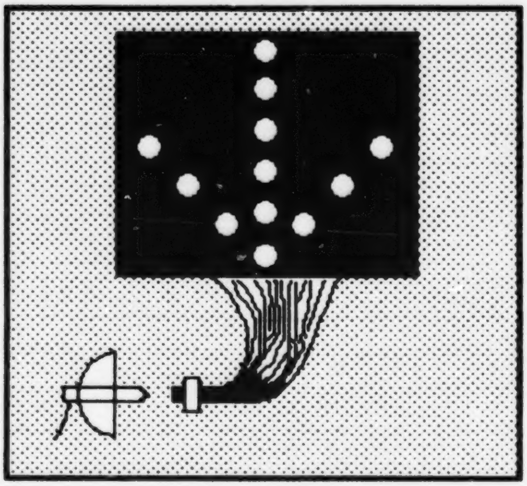


Exhibit 10m

ADVANTAGES AND DISADVANTAGES OF FIBRE-OPTIC MATRIX SIGNS

Advantages
- Relatively simple concept
- Low power consumption
- Different color combinations available
- Both pictorials and highway symbols available

Disadvantages
- Limited number of hard wired (fixed) messages
- Wash out under intense sunlight
- Premature bulb failure (if no voltage regulator)
- Lack of message changeability

10.3

Equipment

The primary components of a freeway driver information variable message sign system are:
- a variable message display;
- a control system for the display;
- a communication system for interconnect techniques between the sign controller and any central computer control; and
- a freeway surveillance system to provide real-time input for the sign.

The specific equipment and the mechanics of the different signs are presented within Section 10.2: Techniques — by Exhibits 10b, d, f, h and l.

10.4 Cost Components

The cost of a driver information signing system is dependent on several factors:

- location of the particular project;
- the manner in which the variable message sign is displayed;
- whether the whole sign utilizes the variable message or whether there are variable message inserts in a sign that also utilizes a fixed message;
- cost of the sign support — which will vary depending upon the size of the individual variable message sign and additional fixed signs that may be mounted to the sign structure;
- cost of the control system — which will vary depending upon whether the variable message sign utilizes a simple control system or a more sophisticated control system;
- cost of the communication or interconnect technique between the sign control and the central computer control (see Chapter 15); and
- the type of freeway surveillance system that is utilized to provide real-time inputs for the sign — which will vary depending upon whether it is part of an overall freeway incident management system or whether a separate surveillance system is designed for one particular location where variable message signs will be installed.

The cost of the various techniques of a driver information signing system may vary tremendously. Since the currently most common variable message signs are either of a lamp matrix or disk matrix type, the detailed cost trade-off information (developed for the Integrated Motorist Information System on Long Island) has been selected for this guide book.

The elements of the cost trade-off analysis for the lamp and disk matrix signs — with breakdowns for capital,operating and maintenance costs — are presented in Exhibit 10n. The trade-off items have been included, for which significant cost differences exist between the two sign types. The cost figures used in the analysis do *not* include portions of the signing system which are common to both types (e.g. mounting structure, protective barriers, etc.) A summary of the trade-off analysis is presented in Exhibit 10o.

While both sign types would have satisfied the functional requirements for IMIS, it was shown that on an overall cost basis (combined capital, operating and maintenance) the disk type would provide significant savings. Also, from the user agency's viewpoint, its operating and maintenance costs were substantially lower. In addition — the minimization of power consumption (an item of current and future national concern in Canada) afforded by the disk-type matrix provides a further advantage. Based upon this trade-off analysis, the disk matrix sign was proposed as the recommended type for the IMIS project.

However, caution should be exercised in accepting the (above) selection of the disk matrix sign as valid for all circumstances. Any future trade-off studies should take into account possible changes in factors being compared — for instance, increasing power costs would tend to favour the disk matrix, while higher interest rates would tend to favour the lamp matrix.

It should be recognized that the function and intended use of the driver information sign will influence the type and size of the sign —and, in turn, will affect the cost of the sign system. It is recommended that, in estimating the costs for a driver information signing system, particular emphasis be placed on the project location, the type of variable message sign, its intended application, and the overall capital, maintenance and operating costs.

Exhibit 10n

ELEMENTS OF COST TRADE-OFF ANALYSIS FOR LAMP AND DISK MATRIX SIGNS

Capital Costs

SIGN CONFIGURATION	UNIT SIGN COST ($)	
	Lamp	Disk
1 Line Insert, 10 char/line	$ 8 000	$ 9 000
2 Lines, 20 char/line	26 000	33 000
3 Lines, 20 char/line	37 000	48 000
4 Lines, 20 char/line	43 000	62 000

Note:

- Capital costs do not include costs common to both types: sign control equipment at system control centre, mounting structure or installation costs.

Operating Costs[1]

	OPERATING COST ($/h)			ANNUAL OPERATING COSTS ($/a)	
	Lamp		Disk		
SIGN CONFIGURATION	Normal Usage	Low Usage		Lamp	Disk
1 Line (Insert)	0.07	0.03	0.05	$ 838[2]	$219[3]
2 Lines	0.29	0.12	0.07	1 796	307
3 Lines	0.43	0.17	0.10	2 628	438
4 Lines	0.58	0.23	0.12	3 548	526

1) Assumptions

- Variable message sign operation — 24 hours/day, message always displayed.
- Normal usage — 12 h/day with 25% of lamps illuminated.
- Low usage — 12 h/day with 10% of lamps illuminated.
- Cost of power = $.06/kWh
- Operating cost of disk due to night illumination.

2) Sample calculation: ($0.07/h x 12h + $0.03/h x 12h)/day x 365 days = $438, plus $400 for external illumination of fixed message part of sign panel (12h/day)

3) Sample calculation: ($0.05/h x 12h (nighttime))/day x 365 days = $219

Maintenance Costs

SIGN CONFIGURATION	ANNUAL MAINTENANCE COST[2] ($/a)	
	Lamp	Disk[1]
1 Line	$ 600	$ 270
2 Lines	1 200	990
3 Lines	1 800	1 440
4 Lines	2 400	1 860

Note:

1) For disk matrix, assumed as 3% of capital cost based on discussions with sign manufacturers.

2) All costs in U.S. dollars

Exhibit 10o

COST TRADE-OFF ANALYSIS SUMMARY

Lamp vs. Disk Matrix Signs

	1-LINE		2-LINE		3-LINE		4-LINE	
SIGN COSTS	LAMP	DISK	LAMP	DISK	LAMP	DISK	LAMP	DISK
A. Capital	8 000	9 000	26 000	33 000	37 000	48 000	43 000	62 000
B. Operating	838	219	1 796	307	2 628	438	3 548	526
C. Maintenance	600	270	1 200	990	1 800	1 440	2 400	1 860
D. Capital Recovery of (A)*	1 052	1 183	3 418	4 339	4 865	6 311	5 653	8 151
E. Total Yearly (B+C+D)	2 490	1 672	6 414	5 636	9 293	8 189	11 601	10 537
F. Current Value of (B+C)	10 938	3 719	22 788	9 865	33 680	14 284	45 241	18 148
G. Total Current Value (A+F)*	18 983	12 719	48 788	42 865	70 680	62 284	88 241	80 148

*Based on 10% interest rate, 15 year life.

Note: Costs are in 1979 U.S. dollars.

10.5 Application Criteria

In comparing the applicability of alternative variable message sign systems to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 10p.

Exhibit 10p
APPLICATION CRITERIA
FOR
DRIVER INFORMATION SIGNS

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS					
	Roller-Shade	Rotating Drum	Lamp Matrix	Disk Matrix	Flap Matrix	Fibre-Optic Matrix
Typical Use						
• Lane control	✓		✓	✓		✓
• Turn movements	✓					
• Variable speed limit	✓	✓	✓	✓		✓
• Traffic advisory	✓	✓	✓	✓	✓	
• Alternate routing		✓	✓	✓	✓	✓
• Inclement weather		✓	✓	✓	✓	✓
• Weigh stations		✓	✓	✓	✓	✓
• Freeway application			✓	✓		
Message Complement						
• Limited number of messages	✓	✓				✓
• Unlimited number of messages			✓	✓	✓	
Cost Considerations (Freeway Application)						
• Initial capital cost			✓			
• Maintenance cost				✓		
• Operating cost				✓		
• Overall cost				✓		
Human Factors						
• Driver readability			✓	✓		
• Minimal confusion during Message changing			✓	✓		

11.
HIGHWAY ADVISORY RADIO

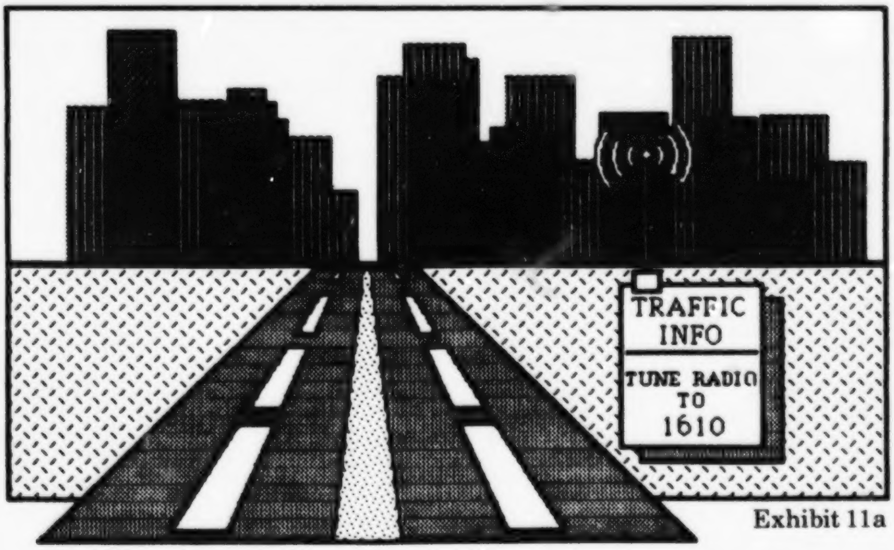


Exhibit 11a

11.1 Concept

Another means of providing information to motorists is through the use of a highway advisory radio (HAR) system or "audio signing". HAR may be used in addition to or as an alternative to variable message signs, to provide motorists with real time traffic information. Signs would be located on the highway facilities advising motorists to tune the car radios to an AM station to receive traffic information on roadway conditions in the immediate area.

Highway advisory radio has been used at Disney World and at the Los Angeles International Airport to advise and direct motorists to parking lots where there are available parking spaces. HAR has also been used successfully in highway construction projects to advise of roadway conditions and alternative routes.

Low power transmitters, located along the roadways, permit information to be broadcast from the central control facility to a localized zone along the highway. In the United States, the Federal Communications Commission (FCC) has allocated the frequencies of 530 kHz and 1610 kHz which are located just outside of the standard AM broadcast bands but which can be received by most AM radios. Possibly, the low frequency could be used for one direction of travel, and the higher frequency used for the opposing direction. The use of 530 kHz or 1610 kHz should be examined based on the presence of commercial radio stations at nearby frequencies.

In Canada, only two HAR systems are presently operated — one in Banff by Parks Canada and the other in Sarnia.

At the Blue Water Bridge, the Ontario Ministry of Tourism and Recreation operates an HAR service directed to American tourists crossing from Port Huron to Sarnia. Each eight minute transmission, run continuously around-the-clock and heard within a 9 km radius of the bridge, offers advise on Canadian traffic laws, currency exchange, events and weather, and on U.S. customs regulations (for returning residents).

The possible opening of frequencies in 1605 kHz-1705 kHz range to public broadcasting which could include travellers information services etc., was subject to public comment during the winter of 1984/85. The findings will be presented at a Medium Frequency Regional Conference in 1986 — for a subsequent decision by the federal Department of Communications.

Where HAR can be used in the place of variable message signs, substantial cost savings can be realized. From a traffic management standpoint, HAR has one distinct advantage over changeable message signs: drivers can be rerouted *well before* they enter a heavily congested freeway section — in fact, often before they leave on their trip. It is never practical, or financially possible, to install enough changeable message signs to achieve a similar effect. In practice, of course, the two systems are likely to be applied together for full flexibility and effect.

There are two possible alternative antenna configurations for a highway advisory radio system:

- Cable radiator antenna
- Monopole whip antenna

Information on these two alternative techniques is presented in the following.

11.2
Techniques

Cable Radiator System

A cable radiator antenna is normally buried in the ground parallel to and in close proximity to the roadway. The system and its coverage zone are illustrated in Exhibit 11b.

A cable radiator antenna is a transmission cable that radiates a near or induction field broadcast signal. The types of HAR cable radiator antennas are shown in Exhibit 11c.

The broadcasting zone of a cable radiator antenna is concentrated along the cable and extends perpendicular to the cable for a distance of 87.5 m at 530 kHz and 29.4 m at 1610 kHz. The configuration of the cable radiator antenna is shown in Exhibit 11d.

The electrical layout for the cable radiator antenna system is a centre feed from the transmitter to a power slitter with the ends of the cable terminated. Only unbalanced coaxial transmission line is used in highway advisory radios with the cable radiator system. The advantages and disadvantages of cable radiator antenna systems are presented in Exhibit 11e.

Exhibit 11b
CABLE RADIATOR ANTENNA SYSTEM

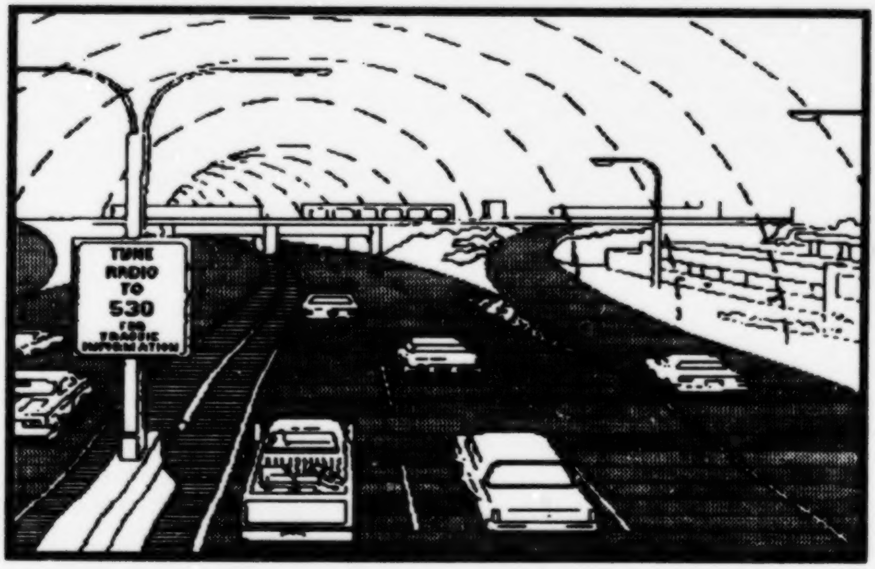


Exhibit 11c

CABLE RADIATOR ANTENNA TYPES

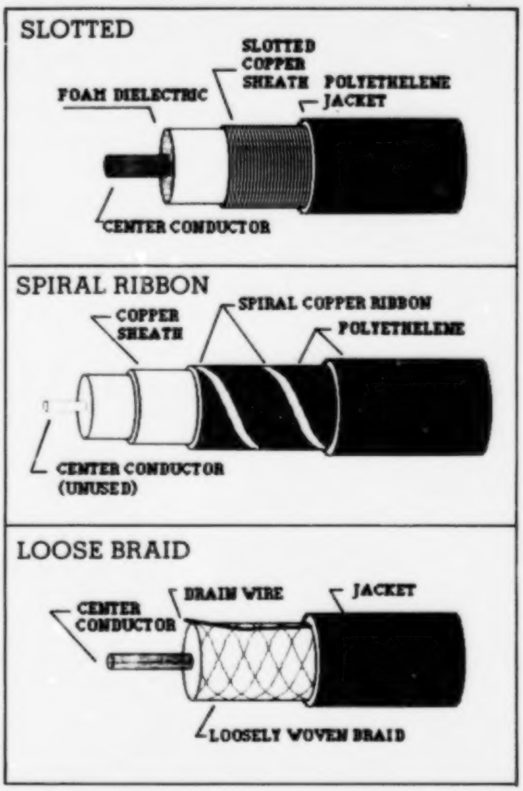

SLOTTED
SLOTTED COPPER SHEATH
POLYETHELENE JACKET
FOAM DIELECTRIC
CENTER CONDUCTOR
SPIRAL RIBBON
COPPER SHEATH
SPIRAL COPPER RIBBON
POLYETHELENE
CENTER CONDUCTOR (UNUSED)
LOOSE BRAID
CENTER CONDUCTOR
DRAIN WIRE
JACKET
LOOSELY WOVEN BRAID

Exhibit 11d

ELECTRICAL LAYOUT FOR CABLE RADIATOR ANTENNAS

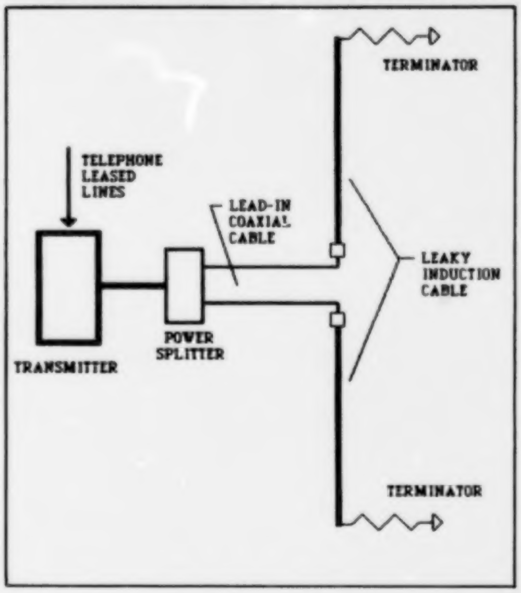

TERMINATOR
TELEPHONE LEASED LINES
LEAD-IN COAXIAL CABLE
LEAKY INDUCTION CABLE
TRANSMITTER
POWER SPLITTER
TERMINATOR

Exhibit 11e

ADVANTAGES AND DISADVANTAGES OF CABLE ANTENNA SYSTEMS

Advantages

- Continuous coverage through tunnels, buildings, under overpasses, etc.
- Not visible to motorists
- Usually connected electrically: requires no matching network or tuning adjustment
- Radiation zone confined within 30m from the cable: covered zone controlled to minimize interference to nearby zones
- Not subject to weather, accidents or vandalism when installed below ground
- Stable radiation in all weather conditions
- Relatively unaffected by type of soil (when buried)

Disadvantages

- Must be placed close to the highway
- Must physically extend the full length of the covered zone
- Must often be installed 15-20 cm below ground
- More costly to purchase, and install (if buried)
- Not easily relocated, if buried
- Not easily installed in some areas already built up with concrete pavement and highway structures, especially through major intersections.

Monopole Antenna System

The monopole whip antenna is a common type antenna that can be mounted to a pole in the vicinity of the cabinet housing the highway advisory radio equipment at the field site. The monopole antenna system and its coverage zone are presented in Exhibit 11f.

A monopole antenna system is comprised of a vertical conductor that is tuned to a particular desired frequency and has a feed to ground. The monopole antenna has a radiation coverage in all directions. Diagrams for ground and overpass structure mounted antenna installations are shown in Exhibit 11g.

The coverage zones of a monopole antenna and a cable radiator antenna are shown in Exhibit 11h. The coverage of the monopole antenna system is directly related to the efficiency of the antenna and the terrain in the vicinity of the antenna field site.

The advantages and disadvantages of monopole antenna systems are contained in Exhibit 11i.

Exhibit 11f
MONOPOLE WHIP ANTENNA SYSTEM

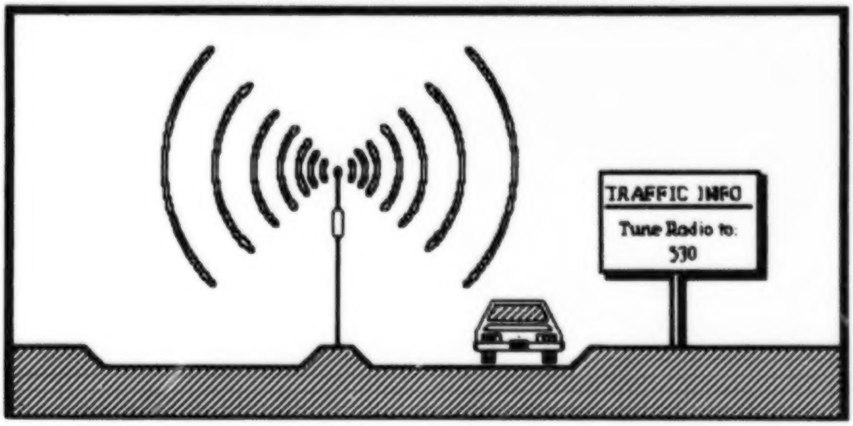

TRAFFIC INFO
Tune Radio to:
530

Exhibit 11g
MONOPOLE ANTENNA CONFIGURATIONS

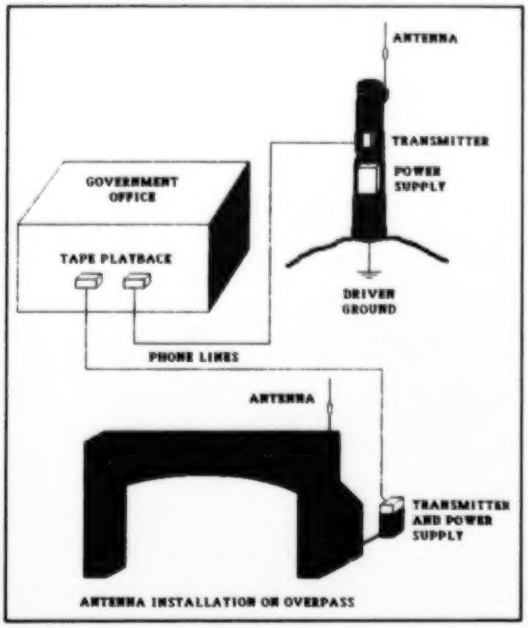

ANTENNA
TRANSMITTER
POWER SUPPLY
GOVERNMENT OFFICE
TAPE PLAYBACK
DRIVEN GROUND
PHONE LINES
ANTENNA
TRANSMITTER AND POWER SUPPLY
ANTENNA INSTALLATION ON OVERPASS

Exhibit 11h
MONOPOLE ANTENNA COVERAGE ZONE

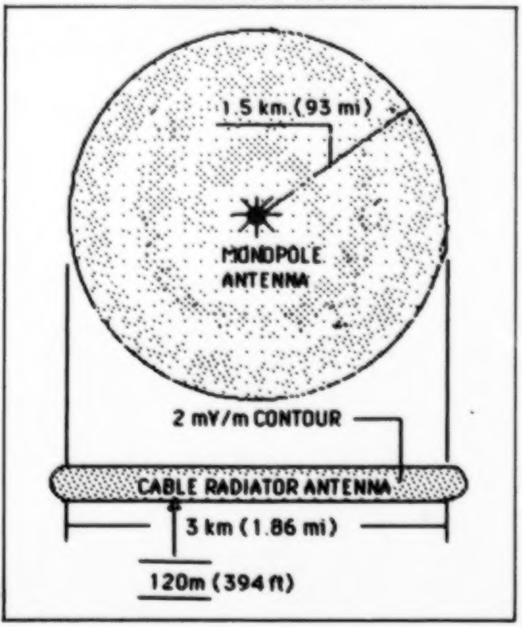

1.5 km (.93 mi)
MONOPOLE ANTENNA
2 mV/m CONTOUR
CABLE RADIATOR ANTENNA
3 km (1.86 mi)
120m (394 ft)

Exhibit 11i

**ADVANTAGES AND DISADVANTAGES
OF
MONOPOLE ANTENNA SYSTEMS**

Advantages

- Physically small: can be installed in a fairly small space
- Relatively easy to install
- Portable: can be easily relocated to another site
- Wide radiation coverage: can be placed over 100m from the highway
- Usually less costly to purchase and install (than a cable radiator antenna).

Disadvantages

- Easily visible: subject to possible vandalism
- Subject to damage by weather and accidents
- Circular, wide zone of coverage: may interfere with other covered zones on adjacent highways.

11.3 Equipment

Control Centre

The primary components of a highway advisory radio system are the broadcast equipment in the control centre, the AM transmitter in the field, and the antenna in the field. In the control centre, appropriate messages can be broadcast by:

a) direct voice of a control centre operator via a microphone system; or

b) a pre-recorded message on a continuously repeating tape.

In a control centre that is staffed by operators, it is possible for the operator to directly interface and broadcast a live message to the field site. However, in small freeway management systems that rely solely on HAR, the costs of providing a full time control operator for live messages could be prohibitive. Indeed, most audio signing systems utilize pre-recorded taped messages. While either a cartridge or cassette system can be utilized, an endless-loop cassette system is generally preferred due to its advantages. The endless-loop cassette operation is used in automatic telephone answering equipment and automatic-dial alarm systems. In continuous-loop recordings, a fixed length tape is wound on a spool and drawn by a capstan and spliced end-to-end so that the recorded material can be repeated continuously. In the future, solid-state voice storage equipment for recording and playback of continuously repeating messages is expected to be used in highway advisory radio systems.

11.4 Cost Components

A cost trade-off study undertaken for the Integrated Motorist Information System in the Northern Long Island Corridor in New York, arrived at the (typical) unit cost estimates for a roadside radio system shown in Exhibit 11j. The costs for the installation of the alternative field antenna systems indicate that a monopole antenna is substantially less expensive than a cable radiator antenna.

The Federal Highway Administration has prepared cost estimates for operating three different highway advisory radio configurations (Exhibit 11k). The operating costs for highway advisory radio systems, provided for:

a) an unattended control centre operation;

b) a part time; and

c) a full time control centre operation.

Exhibit 11j

UNIT COST ESTIMATE FOR ROADSIDE RADIO

SYSTEM ELEMENTS	COSTS
	($ Canada)
System Elements Common to both Alternatives	
Single channel broadcast system, including loop cartridge recorder	3 500
Foundation to support NEMA 12 cabinet, including anchor bolts	325
System installation and test, including placing cabinet on foundation, connecting power and control cables, tuning and final checkout	325
System signing: to identify radio zone and frequencies to tune in	1 950
Antenna Alternatives	
Roadside radiator (1524m typical) cable material @ $3.28/m x 1524m cable burial(1 @ $2.62/m x 1524m	11 700 or
Whip antenna installed, including matching network	650
System Totals	
Cable radiator configuration	17 800 or
Whip antenna configuration	6 750

Note: 1) Roadside radiator cable is assumed to be installed by direct burial 15 to 20 cm in depth, in soft earth.

Exhibit 11k

HAR OPERATING COSTS

LEVEL OF SERVICE	MONTHLY COST
	($ Canadian)
Unattended Site	
Operation and administration	780
Maintenance (in house), or	20
Maintenance (contract)	65
	845
Part-time (Collateral Duty) Site	
Operation & administration	207
Maintenance	13
	220
Full-time Site	
Operation & administration	6 955
Maintenance (contract)	755
	7 710

11.5 Application Criteria

In comparing the applicability of the alternative HAR antenna configurations to specific operating circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 11l.

Exhibit 11l

APPLICATION CRITERIA
FOR
HAR ANTENNA CONFIGURATIONS

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS	
	Cable Radiator Antenna	Monopole Whip Antenna
Roadway Configuration		
• Single linear roadway	✓	✓
• Closely spaced parallel roadways	✓	
• Close adjacent broadcast zones on single or parallel roadways	✓	
• Installation through interchanges and intersections		✓
Mounting/Operational Environment		
• Insulated from conducting surfaces	✓	✓
• Located close to vertical conductors (metal lamp posts, high power transmission lines, etc.)	✓	
• Located close to radiators (guiderails, sign structures, storm drains)		✓
• Located at a distance of 5 times its physical height from vertical conductors	✓	✓
• Presence of soil moisture/content ground conductivity	✓	✓
• Presence of rodents chewing unshielded cable	✓	✓
Interference Zone Between Stations[1]		
• Distance between monopole antennas		
<15 km	✓	
>15 km	✓	✓
• Distance between monopole antenna and cable radiator antenna		
<7.5 km	✓	
>7.5 km	✓	✓
• Distance between cable radiator antennas		
<.5 km		✓
>.5 km	✓	✓
Cost of Antenna Installation		✓
Human Factors		
• Longer installation to ensure driver receive message twice at		
Low speeds		
High speeds	✓	

[1] No minimum separation distances are required by FCC for a co-channel system operating under a single authorization.

12.

IN-VEHICLE GUIDANCE SYSTEMS

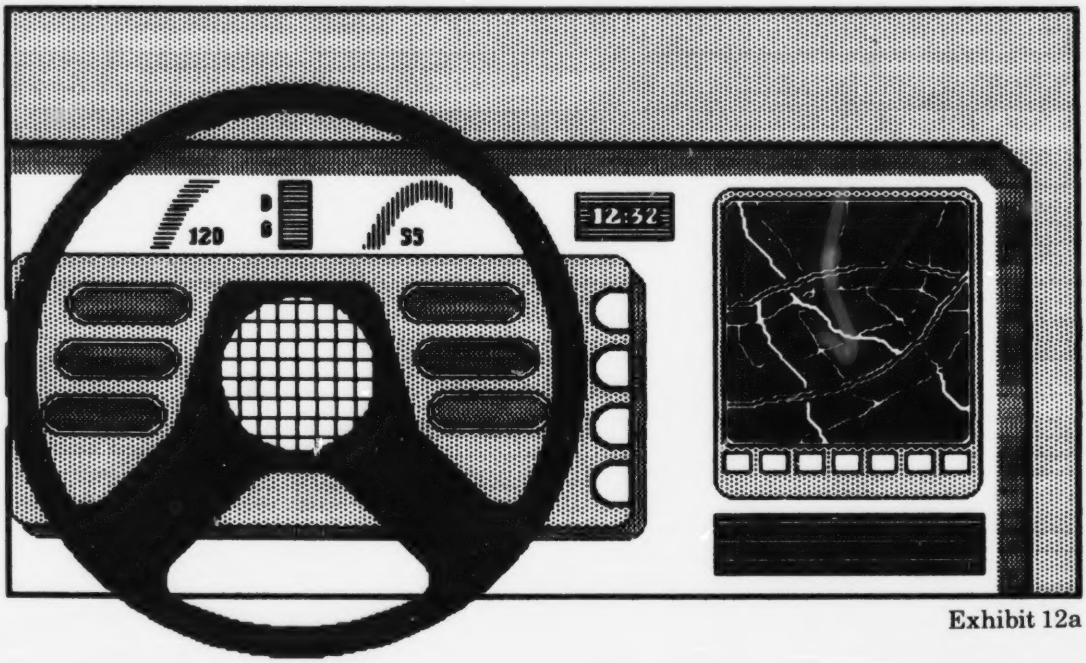


Exhibit 12a

12.1 Concept

Although drivers can be provided information about the travel conditions ahead at various points along a roadway via variable message signs and/or highway advisory radio systems (so that they may choose their travel routes), many drivers would prefer to be provided automatically with specific routing instructions. This concept would facilitate better route selection prior to critical decision points along arterials, freeway entry ramps, etc., and particularly at locations where variable message signs are not being provided. Thus, In-Vehicle Guidance Systems would make it possible, and much easier, for each driver to follow a "best route" to his/her destination.

Several route guidance systems of this type are currently under development, or are already being tested:

DAIR	☐ Driver Aid, Information and Routing;
ERGS	☐ Electronic Route Guidance System;
CACS	☐ Comprehensive Automobile Control System; and
IVRG	☐ In-Vehicular Route Guidance.

In an in-vehicle guidance system, a driver could enter the present location of the vehicle and the intended destination into an electronic device contained in the vehicle. On the basis of current traffic conditions, instructions would then be transmitted to the driver. These instructions could include possible directions to:

a) exit at the next ramp and to proceed to an alternative freeway;

b) turn right and proceed along an arterial roadway; or

c) entirely avoid entering a congested freeway.

Similar up-to-the-minute information would be provided along the entire trip so that each driver could follow a "best route" to his/her destination.

In-vehicle guidance systems usually consist of four primary components (Exhibit 12b):

1. An in-vehicle visual display;

2. A two-way communications system for interface between the vehicle and the roadside;
3. Vehicle detectors; and
4. A central computer control facility.

12.2 Techniques

In-Vehicle Display

An in-vehicle display unit is usually mounted either on the dashboard of the vehicle (Exhibit 12a), or on a separate console (Exhibit 12c). This unit permits the driver to enter the vehicle's present location and the destination of the trip. Then, information on the "best route" will be displayed with updated information being provided along the trip.

Depending on the particular in-vehicle guidance system, information on the present location of the vehicle and the final destination could be input by the driver in the following manner:

- Typing in the information;
- Pressing buttons on a keyboard to enter pre-coded locations;
- Tracing, with a light pen, the route information on a CRT display; or
- Punching in the final destination only, with the present location of the vehicle being automatically noted by a detector or identification unit attached to the vehicle.

Exhibit 12b
INTERACTION OF SYSTEM COMPONENTS

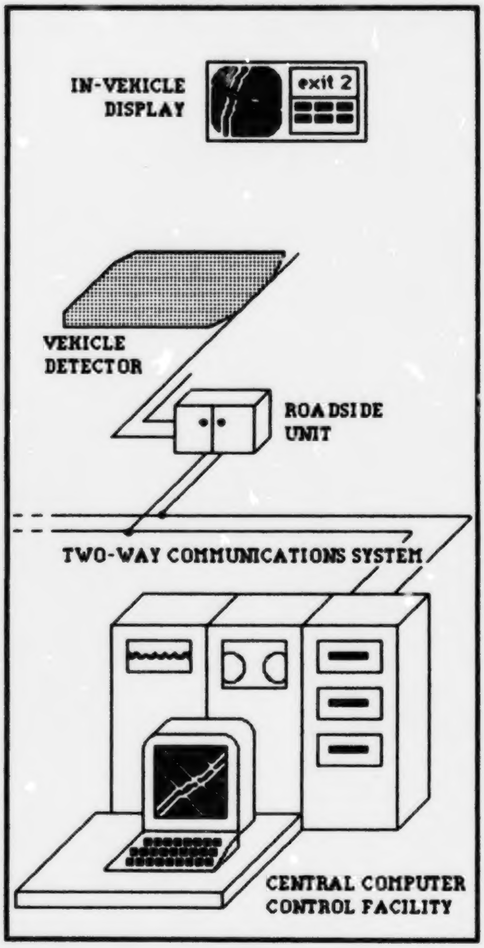
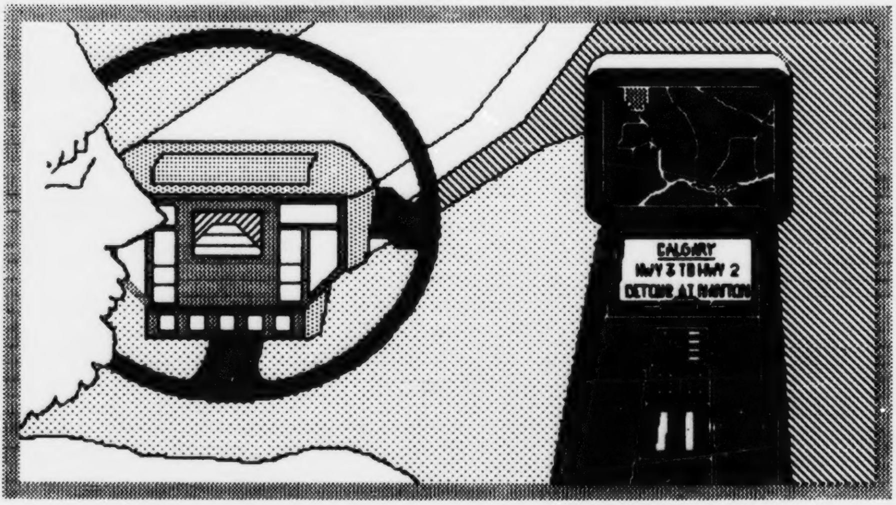

IN-VEHICLE DISPLAY
exit 2
VEHICLE DETECTOR
ROADSIDE UNIT
TWO-WAY COMMUNICATIONS SYSTEM
CENTRAL COMPUTER CONTROL FACILITY

Exhibit 12c
IN-VEHICLE DISPLAY CONSOLE

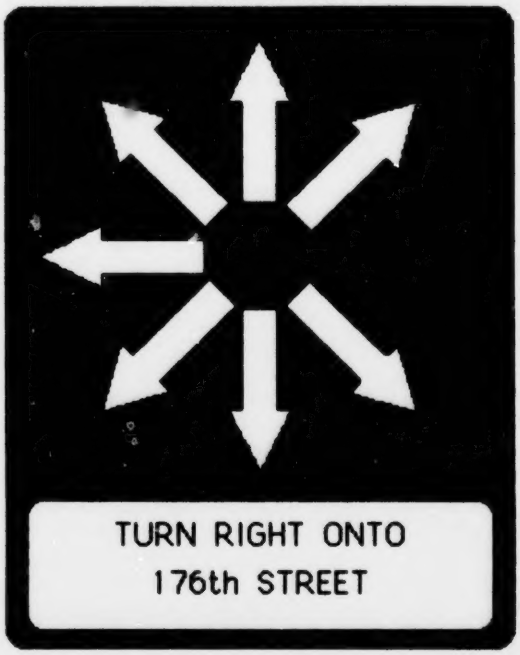

CALGARY
HWY 3 TO HWY 2
DETOUR AT [illegible]

The "best route" information can then be provided from the control centre to the driver in the following forms:

- Printed names of the routes to be used displayed visually on the in-vehicle CRT display unit;
- Coded symbols displayed visually on the CRT display unit at various points along the travel route. For example, a right arrow would advise the driver to turn right at the next intersection (Exhibit 12d);
- Colours displayed visually on an area map presented on the CRT display unit. For example, the best route could be colored in green (Exhibit 12e); or
- Audio messages provided through the speakers of the in-vehicle unit.

In selecting an in-vehicle guidance system, human factors engineering must be very carefully addressed to assure that the display of the messages does not require diversion of a driver's attention away from the driving duties to such an extent that operating the vehicle becomes unsafe. Indeed, the various information transfer techniques will still require further testing.

Exhibit 12d
ELECTRONIC NAVIGATOR TURN INSTRUCTIONS



TURN RIGHT ONTO
176th STREET

Communications Systems

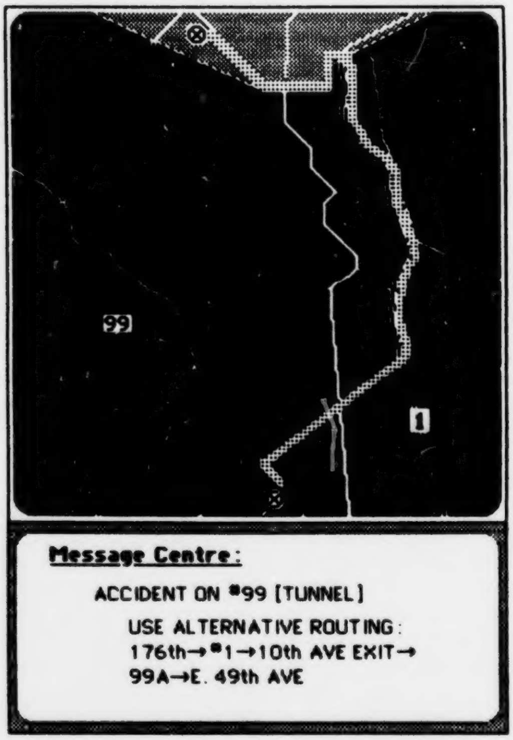
A two-way communications system is required for interface between the vehicle and the roadside unit. This interface can be realized through the following methods:

- Use of a "sending/receiving" unit that will automatically identify the location of the vehicle and permit the sending of information as the vehicle passes over or near the field unit;
- Use of automatic vehicle identification techniques to track each vehicle along its travel route; or
- Use of communications medium to transmit information on the vehicle to the central computer control facility where the determination of the best route will be made.

Vehicle Detectors

Vehicle detectors are attached or located in the vehicle to permit the identification of the location of the vehicle as it travels along the routes of the system. These detectors can utilize the following devices:

Exhibit 12e
ALTERNATIVE COMMUTER ROUTING
Display & Instructions



Message Centre:

ACCIDENT ON #99 [TUNNEL]

USE ALTERNATIVE ROUTING:
176th→#1→10th AVE EXIT→
99A→E. 49th AVE

- A separate identification unit attached to the body of the vehicle;
- A separate part attached to the in-vehicle display unit; or
- A small electronic sending unit that could be coded and distributed as part of the registration or inspection sticker.

Central Computer Control Facility

The central computer control facility receives the information requested by the driver that is transmitted from the roadway field units. Based on real-time information on roadway conditions that are available from the electronic surveillance techniques, the computer decides on the best route and transmits this information back to the field, and the in-vehicle guidance display, where the information is presented to the driver.

12.3

Equipment

While complete in-vehicle guidance systems are not yet marketed anywhere in the world, it has been projected that — by the end of the decade — all three major U.S. and several overseas vehicle manufacturers will offer these systems as options for their top line cars. This will come about simply as part of a much wider trend to equip vehicles with electronic sensors and on-board computers. For example, in some of GM's 1986 models up to 7 computers are forecast to handle some 38000 command instructions (as opposed to 4000-8000 commands in 1983).

One of the electronic navigation systems being presently developed is Chrysler's "CLASS" —or Chrysler Laser Atlas Satellite System (installed in their Stealth concept car). The system is based on the U.S. government's NAVSTAR system which is scheduled to expand to 18 orbiting satellites from the current 5 by 1988. In each vehicle, the on-board computer must receive a signal from 4 satellites simultaneously in order to calculate the vehicle's actual position — to be provided in four diminsions: latitude, longitude, altitude and time. The position, accurate within 100m (vs. 15m for a coded signal of the military), will be transmitted to the driver by displaying the corresponding map and a vehicle icon on a CRT (cathode ray tube) touch screen monitor. The full colour maps, some 13000 for the U.S. (covering 100km^2 — 10000km^2 each), are stored on one optical laser video disk. Since one 8 inch disk can handle 25000 four colour images on one side, the system could offer enough maps to cover Mexico and southern Canada, and for zooming into details within metropolitan areas — as well as a great variety of related travel information (list of motels and their rates and locations, tourist attractions, etc.) and possibly the content of an owner's manual.

Etak Navigator System — scheduled for production in 1985 — uses no external system such as satellites or radar. It has a digital magnetic compass, motion sensors, and a computerized "smart" dead-reckoning system — which, by measuring courses and distances travelled, together determine where the vehicle is at all times. The system allows viewing of large areas or zooming in to a street network level — a 400m square area with street names directly on it, which has been digitized and stored on cassettes. Zoom is the only control that can be operated when the vechicle is moving. The destination address is punched in with a 2-step/2-minute process using:

- — speller buttons on the CRT for 3 first letters of closest intersection; and
- — select & scroll buttons to select street name from index list appearing on the CRT.

The CRT map then automatically scrolls and changes directional orientation — keeping the vehicle triangle symbol stationary at the centre and a flashing destination star "ahead" (=up centre).

The accumulated dead-reckoning error is corrected, once every second, by a comparison of distances measured to distances on the map data base — which allows an actual correction in the vehicle's position at each clear turn.

The projected price in U.S. will be $1600 for model #700 (18cm screen) and $1400 for model #450 (12cm screen). Map cassettes will cost $35 each. Installation and initial calibration is estimated to cost $200.

NRV-II, a navigation system developed by Nissan, is being presently installed in a fleet of delivery vans of a department store. Using a floppy disk and a video terminal, each driver can check the vehicle's position within Tokyo, the places he/she will have to go and the most effective delivery route. A planned extension of the system will allow the dispatcher to see the location of every vehicle on a large display board at the dispatch centre.

Several other manufacturers are developing concept vehicles (or 'active testbeds') which include in-vehicle guidance systems:

- GM : Buick Questor
- Ford : Continentel Concept 100 & Comtech Mark VII
- Mazda : MX-02
- West German manufacturers with
  - — Siemens Electric Ltd: VW Auto Scout
  - — VDO
  - — Blaupunkt EVA
- Renault : Dialog

12.4 Cost Components

Until full scale manufacturing and marketing take place, there can be no reliable estimates for the component costs of the various in-vehicle guidance systems. The industry sources do estimate, however, that if the final customer cost can be kept within $2000-$2500, a significant market could be found for these systems as options for the luxury and personal and fleet vehicles — and, most probably, for heavy transport trucks.

Due to expected advances in manufacturing processes, and the stiff competition emerging already at the development stage, a price range of $500-$1000 may not be entirely out of reach of the manufacturers. This would make the in-vehicle guidance systems, perhaps by 1990, ready for the mass markets.

The final (total system) costs for developing, installing and operating complete guidance systems for metropolitan areas will depend on how much of the installation can be considered simply as an add-on to all other traffic control systems — or what share of the costs of vehicle detectors, roadside transmitters and receivers, the communications linkages, central computer control facilities, etc. should be allocated as direct back-up to the in-vehicle guidance system.

12.5 Application Criteria

Since the various in-vehicle route guidance systems are still under development, no proper comparison of the alternatives can be presented at this time. However, in order to assist engineers in reviewing the suitability of such systems, a preliminary set of application criteria has been developed (Exhibit 12f).

In comparing the performance of alternative systems, a rating of Low/Medium/High (and N/A for Not Applicable), or a rating from 1 to 10, might be used against each criteria. Once multiplied with the relative weights given to each criteria, a simple addition of corresponding points would give one indication of which system is preferable for a specific situation.

The criteria are presented only as a guideline for comparing alternative types of systems —and should be used along with the application of good engineering judgement for each particular location.

Exhibit 12f

APPLICATION CRITERIA
FOR
IN-VEHICLE GUIDANCE SYSTEMS

APPLICATION CRITERIA	PERFORMANCE OF SYSTEM	
	System 1	System 2
Overall System Requirements		
• Probability of being selected for widespread use throughout Canada (& U.S.)		
• Usefulness in urban and rural locations		
• Currency of information provided		
• Reasonableness of capital and operating costs to municipality and province		
• Reasonableness of cost to users		
In-Vehicle Display		
• Conformance with current (& likely) national standards		
• Degree of visibility		
• Ease of interpreting given information		
• Conformity with primary driving functions (non-distracting)		
• Adaptability to driver input		
Communications & Detection Systems		
• Ease and range of driver input		
• Responsiveness to real-time information feed		
• Compatability with existing traffic surveillance and control systems		
• Automatic identification of individual vehicles		
• Variety of information transmittable to individual vehicles		
Central Computer Control Facilities		
• Extent of real time information on traffic conditions (as input for determining best routes)		
• Availability of memory (RAM & storage) for handling requirements of individual vehicles		
• Simplicity & flexibility of software for responding to future requirements		

13
PRE-TRIP PLANNING SYSTEMS

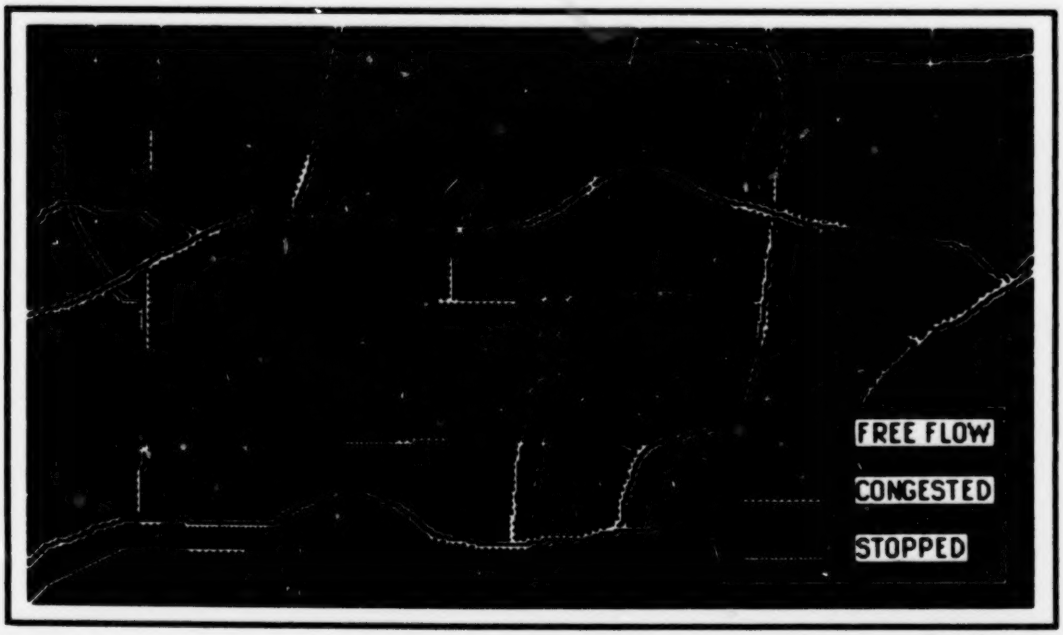


Exhibit 13a

13.1 Concept

Oftentimes the driver may desire to obtain information on roadway conditions prior to initiating a trip. Based on information on the actual conditions, the driver may select a travel route that avoids unusual traffic congestion and results in the shortest travel time to the final destination. Furthermore, during unusual conditions such as severe snow storms, highway agencies can also communicate with surrounding businesses to advise of the best time to release employees so that heavy traffic will not interfere with snow plowing operations.

The most important requirement in all pre-trip planning systems is that the information disseminated is current. If the information is *not* updated constantly, and users find the traffic conditions different from what was described, they will quickly start ignoring the system.

The various techniques that can comprise a pre-trip planning system are discussed in the following section of this chapter.

13.2 Techniques

Telephone Call-In Number

By dialing a special telephone number prior to initiating a trip, a traveller can obtain information on current roadway conditions via a pre-recorded message (Exhibit 13b). By dialing a seven digit number, the caller would be connected to the traffic information service. Then the caller would dial two additional numbers corresponding to the pre-coded areas along the roadway for which information is desired. In large size systems, covering entire metropolitan areas, several telephone numbers could be established to correspond to different major roadways or travel corridors (of parallel roadways).

Similar telephone dial-in systems already exist for the purposes of urban transit systems — where, by dialing a central information number and additional numbers indicating the nearest bus stop, the caller will receive an automatic message stating the arrival time of the next bus. The technique is also similar to the telephone weather numbers that provide weather information.

Information disseminated by telephone must be kept up-to-date so that the motorists find it reliable. A dial-up system installed as part of the Dallas Freeway Management System was discontinued after a trial period because of lack of use by the public. The most frequent reason given by the public in a survey was that freeway conditions would change between their call and their arrival at the freeway.

Teletype Communications System

In order to establish communications with news media and major traffic generators, such as major employers, sports stadiums and other recreational facilities, teletype equipment can be located at these facilities. This will make possible the provision of current traffic information from the traffic control centre. At the sports stadium, information on traffic conditions could be displayed on the scoreboard (Exhibit 13c).

Cable TV Traffic Station

Through the use of colour graphics on CRT screens, it is possible to visually display traffic conditions on a roadway diagram. Thus, conditions on roadway sections can be indicated in:

a) green for free-flow or no congestion conditions;
b) yellow for slowed conditions; and
c) red for stop-and-go conditions.

This information can be transmitted from the control centre to a separate cable television station that will continually broadcast the traffic information. Thus, a traveller could obtain up-to-the-minute traffic information from the television station just prior to initiating a trip (Exhibit 13d).

Exhibit 13b
TELEPHONE TRAFFIC REPORT

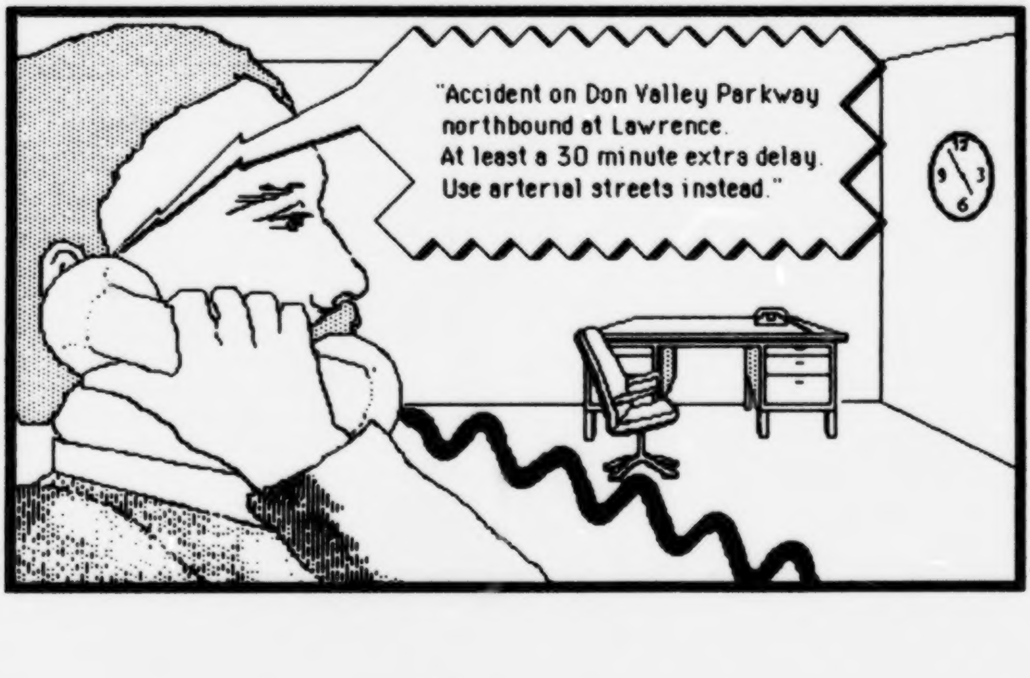

"Accident on Don Valley Parkway northbound at Lawrence. At least a 30 minute extra delay. Use arterial streets instead."
12
9
3
6

Exhibit 13c
SPORTS STADIUM DISPLAY

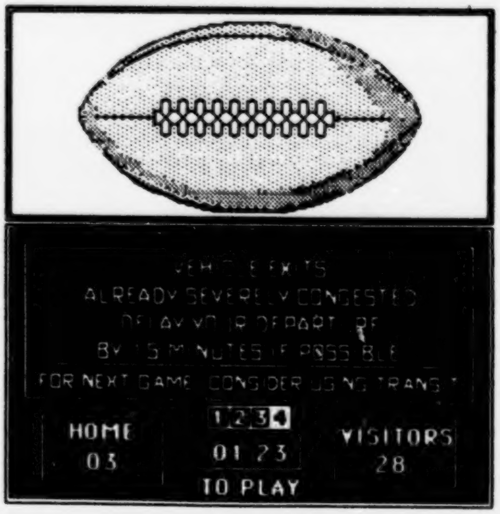
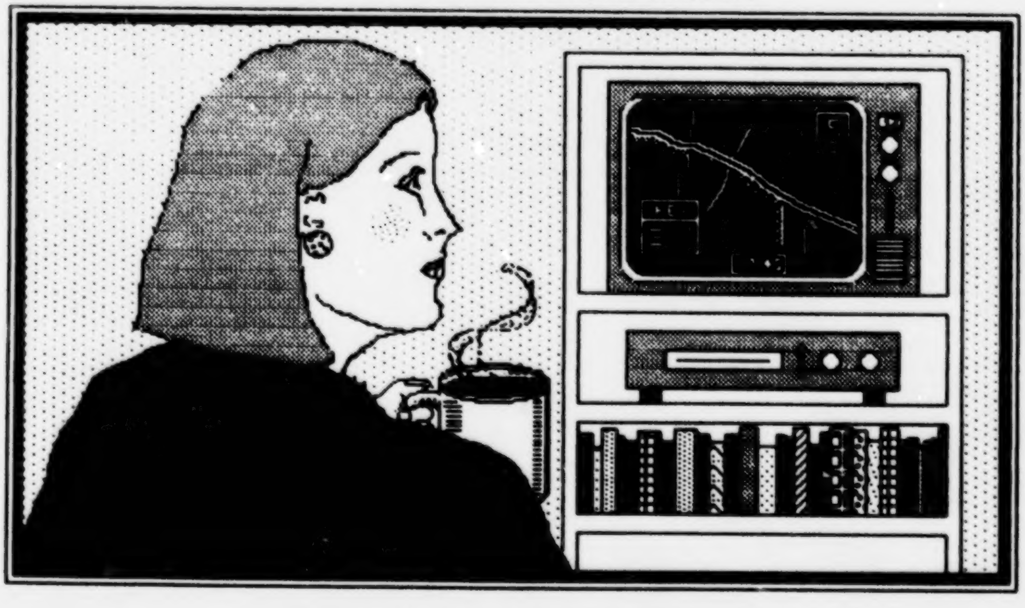

VEHICLE EXITS
ALREADY SEVERELY CONGESTED
DELAY YOUR DEPARTURE
BY 15 MINUTES IF POSSIBLE
FOR NEXT GAME CONSIDER USING TRANSIT
HOME
03
1 2 3 4
01 23
TO PLAY
VISITORS
28

Exhibit 13d
TELEVISED TRAFFIC INFORMATION



Traffic Information Reporting System

In the central business district of a city, a pretrip planning system can be established where information can be posted on large display panels in the lobbies (or at the exit ramps) of and parking garages. During the p.m. departure time periods, up-to-the-minute traffic information can be posted on large display panels in the lobbies (or at the exit ramps) of these buildings so that motorists can plan on using routes that do not have incidents, or have less congestion and delays. An installation at a parking facility is shown in Exhibit 13e.

13.3

Equipment

Telephone dial-up equipment may be leased from the local telephone company. The equipment leased would consist of recording and playback units for each line, a leased line for each pre-recorded message, and a telephone for inputting the message and monitoring it.

Other information disseminated to cable TV, radio stations, sports or recreational facilities, or large employers, could be made available by teletype, CRT/printer, or telephone. With each method of transmission, equipment would be required at the central control facility to send the information out, and compatible receiving and display units would be required at the receiving end. Equipment costs at the central control facility would be charged to the freeway management project while it would be the responsibility of the receiver of the information to purchase and maintain the reception equipment.

Exhibit 13e
PARKING GARAGE DISPLAY

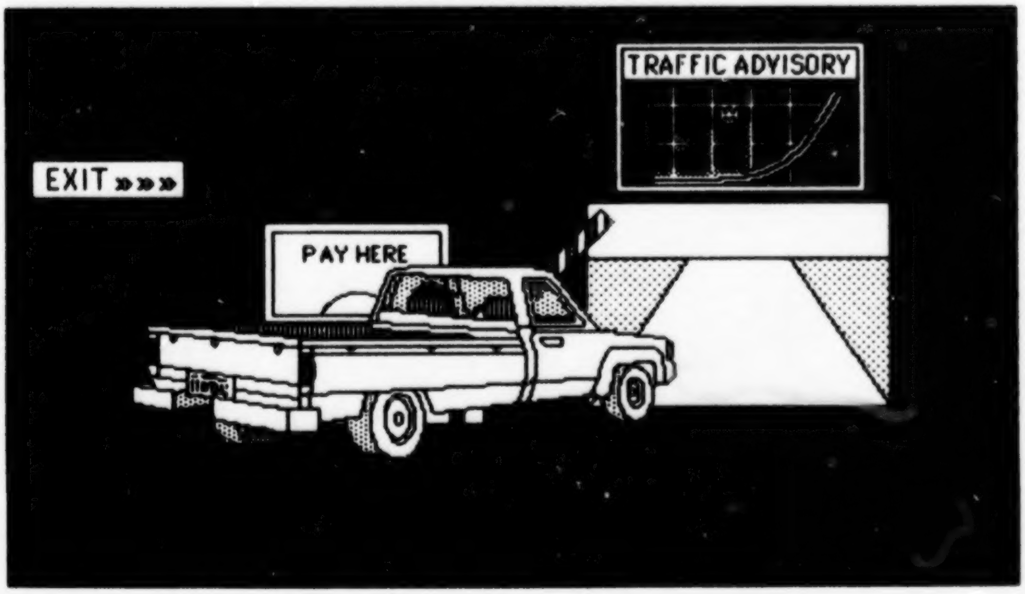


Exhibit 13f

COST COMPONENTS FOR PRE-TRIP PLANNING SYSTEMS

ALTERNATIVE TECHNIQUE	COST ALLOCATION
Telephone Call-in Number	
• Establishment of telephone number	Telephone company
• Message recording	Government agency
• Advertisement of service	Government agency or telephone co.
• Phone call	User charged for each call by telephone company
• Provision of information by government agency	No charge
Teletype Communications System	
• Teletype equipment purchase	Firm or facility using service
• Leased telephone communications	Firm or facility using service
• Dissemination of information	Firm or facility using service
• Provision of information by government agency	No charge
Cable TV Traffic Station	
• CRT display at TV station	Cable TV station
• Communications link (telephone modem interface)	Cable TV station
• Provision of information by government agency	No charge
Traffic Information Reporting System	
• Equipment to receive information (telephone, teletype, CRT)	Firm or facility using service
• Leased telephone communications or telephone modem	Firm or facility using service
• Dissemination of information	Firm or facility using service
• Assurance of latest information posting	Firm or facility using service
• Provision of information by government agency	No charge

13.4 Cost Components

The installation and operating costs of each of the techniques can be considered relatively low. The main components in implementing the alternative techniques, and the agencies/-firms which typically assume the financial responsibilities, are presented in Exhibit 13f. The major portion of the costs is charged to either the firm or facility using the service, or to the individual requesting the information. This exhibit has been compiled on the basis of an existing traffic surveillance and control system that has a central computer control room that can provide the latest reliable traffic information. A breakdown of approximate costs for the various types of transmission and reception equipment is presented in Exhibit 13g.

Exhibit 13g
EQUIPMENT ELEMENT COSTS

EQUIPMENT	COST ($)
Telephone Call-in Number	
• Leased line ($/year/line)	600
• Message recording & Transmission device	250
Teletype	5 000
CRT/Printer	
• CRT	3 000
• Printer[1]	3 000
• Telephone modem	1 000

Note:
1) Required only at reception points, if desired.

It should be recognized that a human interface is required in order to receive and disseminate information at the receiving end for the teletype communications system and the traffic information reporting system. Personnel will also be required for a cable TV traffic station system.

13.5 Application Criteria

In comparing the applicability of alternative pre-trip planning techniques to the specific objectives and requirements at a particular implementation site, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 13h.

Exhibit 13h

APPLICATION CRITERIA FOR PRE-TRIP PLANNING SYSTEMS

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS			
	Telephone Call-In Numbers	Teletype Communi-cations System	Cable TV Station	Traffic Information Reporting System
Provision of Information				
• Single roadways	✓	✓	✓	✓
• Multiple roadways	✓	✓	✓	✓
• During a.m. peak hours	✓		✓	
• During p.m. peak hours	✓	✓	✓	✓
• During off-peak hours	✓	✓	✓	
• Real-time up-to-date information provided	✓	✓	✓	✓
• Real-time up-to-date information displayed	✓	✓	✓	✓
• Human interface required (from a firm or agency) to receive and display information	N/A	✓		✓
Audience to be Provided Information				
• Employees at major work traffic generators (offices, plants)	✓	✓		✓
• Patrons/fans at major recreational facilities (sport complexes, beaches)	✓	✓		✓
• News media		✓	✓	
• General public at home (prior to initiating trip)	✓		✓	
High Accessibility to Users				
Cost				
• Relatively low cost	✓	✓	✓	✓
• Cost to motorists	✓			
• Cost to firm or facility using service	✓	✓	✓	✓
• Cost to government agency	✓			

Note:

1) Information must be kept up-to-date by firm or facility posting the reports.

N/A = Not Applicable

14.

ARTERIAL SIGNAL SYSTEMS

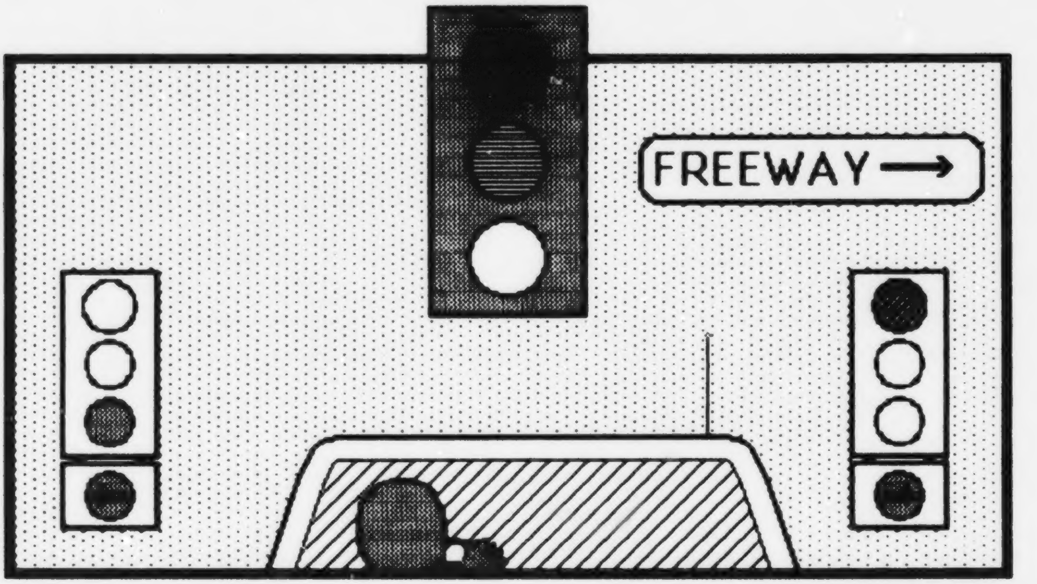


Exhibit 14a

14.1 Concept

An arterial signal system is often included as part of the freeway management system in locations where traffic will periodically need to be diverted from the freeway onto the (parallel) arterials. In addition, traffic signal systems may be implemented on service roads that are adjacent to many freeway facilities.

In essence, the traffic signals on the arterial roadways that are included in a freeway management system are brought under some form of central computer control. The primary reason is to maximize the available throughput capacity of the arterial roadway(s) during times when traffic is diverted from the freeway core lanes. The implementation of the computerized signal system on the arterial also provides significant benefits during all time periods when the system is operational.

The installation of surveillance detectors on the arterials is necessary to provide the real-time traffic data required for both responsive arterial signal control and overall system control. The detection system permits the observation of the traffic conditions on the arterials in order to determine if there is available capacity to absorb the diverted traffic.

There are two basic forms of arterial signal control — hierarchical and centralized. A brief summary of each is presented in the following.

14.2 Techniques

Hierarchical Control

In a hierarchical computerized signal system, the local intersection data is transmitted between the local intersection controllers and a master controller. Each master controller is in charge of a number of local controllers. The master controllers transmit data to the central computer which in turn transmits commands to the master controllers. The master controllers then communicate these commands directly to each of the localized intersections.

(A schematic diagram is presented in Exhibit 14b).

The hierarchical approach provides all processing of raw data at the local controllers, and therefore unburdens the central computer. The hierarchical approach provides a sophisticated backup capability. It also requires much less data to be communicated to central, thereby minimizing communications band width requirements. The advantages and disadvantages of hierarchical control are presented in Exhibit 14c.

Exhibit 14b
HIERARCHICAL SYSTEM
Schematic Diagram

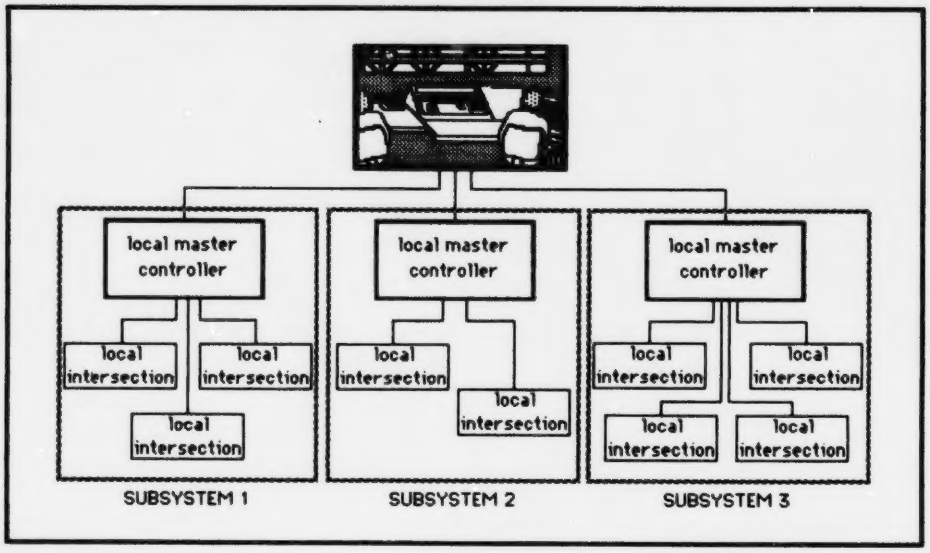

local master controller
local master controller
local master controller
local intersection
local intersection
local intersection
local intersection
local intersection
local intersection
local intersection
local intersection
local intersection
SUBSYSTEM 1
SUBSYSTEM 2
SUBSYSTEM 3

Exhibit 14c

ADVANTAGES AND DISADVANTAGES OF HIERARCHICAL CONTROL

Advantages

- Limited number of prestored timing patterns at either the local master or central master level
- Detector data preprocessed at local master: minimize communications requirements and sizing at central computer
- Individual intersections controlled by local masters: minimize communications requirements to central
- Down loading of pattern changes from central provided
- Sophisticated traffic actuated control of local intersections in the event of communications failure to central
- Standby time-based local control in the event of a total communications failure
- Low cost telephone communications between a local master and central controller feasible over great distances: allowing central supervision (which would not normally be economically viable)

Disadvantages

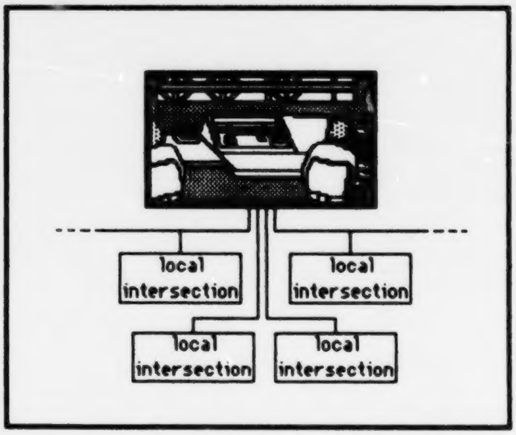
- Critical intersection control not available
- Pattern down loading to local intersections not available
- Cost of the local masters
- Hard to adapt to improvements in central software (such as interactive pattern generation)

Centralized Control

A centralized computer control traffic signal system consists of local intersection controllers communicating directly with a central computer in the computer control room (Exhibit 14d). Since the central computer communicates directly with the local controllers at each intersection, more detailed information is available on the operation and equipment status of each intersection at the central control room.

Since the major portion of the sophisticated control software resides in the central computer, as opposed to the master controller in the field, the flexibility to modify or replace software control algorithms is better in the centralized configuration. In the centralized approach, a theoretically unlimited number of signal timing patterns are available, while in the hierarchical approach the number of signal timing patterns is generally limited to those that are available in the master controllers. The advantages and disadvantages of centralized control are presented in Exhibit 14e.

Exhibit 14d
CENTRALIZED CONTROL
Communications with Local Controller



14.3 Equipment

The equipment necessary for the implementation of an arterial signal system can be divided into two categories:

- the traffic signal equipment (exclusive of the controller); and
- the controller and co-ordination equipment.

Equipment in the first category consists of the following elements:

- Traffic signal heads
- Traffic signal head support system
  - — steel, prestressed concrete or timber strain poles and span-wire
  - — steel mast arms
  - — steel and aluminum pedestal poles
- Roadway detectors
  - — loop detectors
  - — magnetic detectors
  - — pressure pads
  - — magnetometers
- Pedestrian push buttons
- Pullbox and conduit system
- Cable plant.

Exhibit 14e

**ADVANTAGES AND DISADVANTAGES
OF
CENTRALIZED CONTROL**

Advantages

- Unlimited number of signal timing patterns permitted
- Critical intersection control available
- Standby-time based local control available — in the event of a communications failure
- Adaptable to improvements in central software (such as interactive pattern generation)

Disadvantages

- Increased communications requirements
- Increased size of central computer: to accommodate data processing and pattern implementation
- Sophisticated traffic actuated backup of a local system not available

The second category consists of the controller, cabinet, detector amplifiers and co-ordination/communication equipment. The selection of this equipment is dependent on the type of arterial system selected.

The need for a traffic signal is independent of the implementation of an arterial signal system as part of a Freeway Management System. The equipment in category one as well as a controller, detectors and a cabinet most likely exist in the field as part of the present signalization of the intersection. Thus, the costs of these elements are not assigned to the arterial signal system of the Freeway Management System.

The basic equipment necessary to bring an individual signal into an arterial system depends on the choice of either a hierarchical type system or a centralized control system — and, in each case, includes the following:

- Hierarchical control
  - — co-ordination unit at each traffic signal located in the controller cabinet
  - — local master controller
  - — communications unit located at the local master
- Centralized control
  - — coordination/communications unit at each traffic signal.

14.4 Cost Components

It is difficult to present a relative cost comparison for the hierarchical approach versus the centralized control approach because site specific factors can so significantly influence the costs. The type of communications system that is in existence, or is being planned for a freeway management system, can influence the choice of the arterial traffic signal control system. The configuration of the existing traffic signal systems, and the amount of interconnect that exists along with the proposed level of sophistication of the control provided by existing master controllers, will also impact the cost comparisons and the final decision making.

In establishing guidelines for one major (U.S.) freeway traffic surveillance and control system — the Integrated Motorist Information System — it was recommended that the centralized traffic control approach be assumed for cost estimating purposes during the feasibility studies. If long distances of interconnect already exist, the costs may be overstated by this method. However, costs for the two alternatives are expected to be relatively close when little interconnect exists — because of the need to add master controllers as part of the master/central approach. Although controller and communications interfacing are required for the centralized approach, these costs are relatively small and can be viewed as insignificant in relative cost comparisons.

In the Integrated Motorist Information System, the communications linkage for the arterial signal system was designed as a coaxial cable — which permitted the use of the centralized control approach due to the wide bandwidth available on this cable media. The close relative costs were overshadowed by the fact that a redundant backup communications system for the mainline expressway was provided by connecting to the parallel arterial traffic control system.

During the implementation of an arterial signal system, it is likely that all of the control equipment would be replaced to assure compatibility with the coordination/communication unit. The various cost elements of the change over from an independent signal control to an arterial signal control (exclusive of the elements covered in the communications subsystem discussed in Chapter 15) are presented in Exhibit 14f.

14.5 Application Criteria

In comparing the applicability of alternative arterial traffic signal system control approaches to specific local traffic management circumstances, several criteria must be considered. These criteria, together with an initial indication of applicability, are presented in Exhibit 14g.

Exhibit 14f
APPROXIMATE COSTS FOR ARTERIAL SIGNAL SYSTEMS

COMPONENT	COST ($/EACH)
• Traffic signal controller including cabinet	
— 2 phase	5 000
— 3 phase	8 000
— 4 phase	12 000
• Detector amplifiers	250
• Coordination/communication unit (centralized)	2 500
• Local master (hierarchical)	10 000
• Communiations unit (hierarchical)	1 500
• Coordinations unit (hierarchical)	2 000

Exhibit 14g
APPLICATION CRITERIA FOR ARTERIAL TRAFFIC SIGNAL CONTROL

APPLICATION CRITERIA	CENTRALIZED	HIERARCHICAL
Functional requirements		
• Pattern selection from central	✓	✓
• Implementation of unlimited patterns	✓	
• Critical intersection control	✓	
• Sophisticated traffic actuated backup system		✓
• Time based backup system	✓	✓
Surveillance Data		
• Collects data on arterial conditions	✓	✓
• Preprocesses data		✓
• Central processing of data	✓	
Communications System		
• Agency owned cable system	✓	✓
• Leased line cable system		✓[1]
• Dial-up system		✓
Central Computer Control Facilities		
• Ability to monitor surveillance data & implement pattern changes	✓	
• Ability to implement unlimited number of patterns	✓	✓
• Ability to implement critical intersection control	✓	
• Ability to download information to local controllers	✓	✓
System Type[2]		
• Integrated surveillance and control with agency owned communications system and arterial signal system	✓	
• Arterial signal control only (without critical intersection control)		✓
• Arterial signal control only (with critical intersection control)	✓	

Notes:

1) Can apply to both alternatives, but hierarchical is considered economically superior.

2) Centralized control is preferable with large integrated systems due to its flexibility and its ability to utilize critical intersection control. Furthermore, the presence of a communications system for the freeway surveillance and control system permits economical expansion for centralized control of the traffic signals.

15.
COMMUNICATIONS SYSTEMS

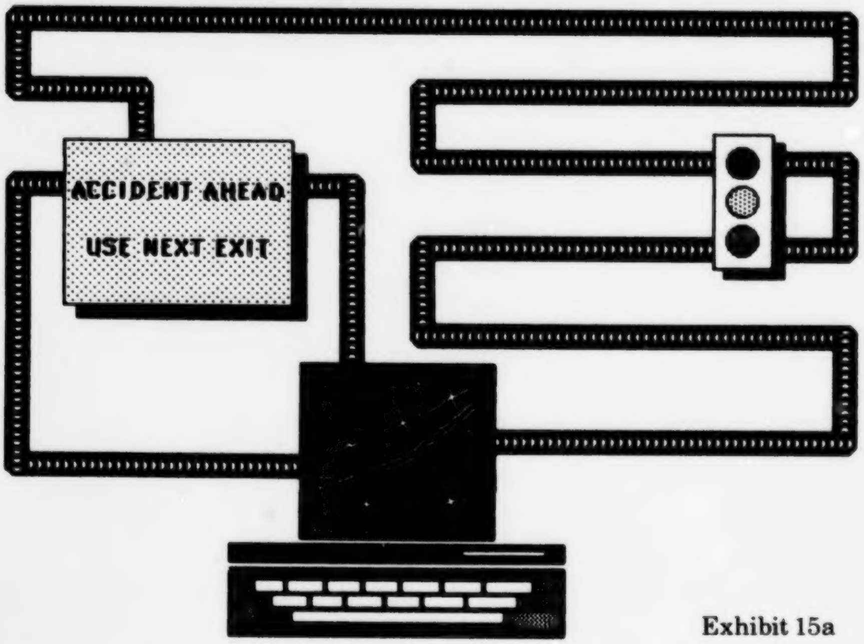


Exhibit 15a

15.1 Concept

In order to transfer information from the various field components located throughout a project site to the central computer control room, a communications medium is required. This communications medium will also transmit responses and commands back to the various field components.

The communications system is one of the most important elements in a freeway management system as well as the most costly. The type of communications system chosen is dependent on the size and complexity of the overall freeway management system configuration — and can greatly affect the selection of individual system components. Preprocessing of data at field locations reduces the communications requirements but adds to the complexity and cost of field equipment. Selection of hierarchical signal control over central control greatly reduces communications requirements but also reduces the flexibility of control.

15.2 Techniques

Types of Medium

There are various types of communications medium that can be utilized in freeway management systems. The selection of the best type is dependent upon the local site's specific conditions and the various control techniques in the system. The primary communications mediums that are used in freeway management systems are:

a) twisted wire pairs;
b) coaxial cable;
c) fibre optics cable;
d) radio transmission.

The major factors to be considered, in addition to cost, in selecting a communications approach are reliability, maintainability, and flexibility for expansion or change.

In the preparation of a trade-off study of coaxial cable versus twisted pair cable, the following factors (which may lead to the selection of the coaxial cable) should be considered:

- rising cost of copper,
- increased labor cost for cable handling,
- recent technological advances in trunk line amplifiers in the cable T.V. industry — which have yielded a greater reliability and lower costs;
- increased flexibility and reliability through automatic switching in the event of a cable cut; and
- greater expansion capability due to wider bandwidths.

In comparing coaxial cable to fibre optics cable, recent technological advances should be recognized as well as the fact that many major telephone utility companies are expanding their use of fibre optics cable.

Radio transmission consists of the transmission of signals of a specific frequency via a radio signal to a transmitter located at central. The signal can be carried over long distances without the construction of a hardwire system. The unavailability of frequencies at a specific location can preclude the use of radio transmission.

The main advantages and disadvantages of the alternative communications mediums are presented in Exhibits 15b-e. The three alternative cable mediums are illustrated in Exhibits 15f/g/h.

Twisted Pair Transmission

In employing twisted wire pair cables, the following three transmission techniques are available:

- Frequency Division Multiplexing (FDM);
- Time Division Multiplexing (TDM); and
- Direct Current Switching (DCS).

Fibre Optic Cable Transmission

Fibre optic cable transmits data and video signals utilizing several different types of transmitting and receiving systems. Each system offers certain advantages and disadvantages. A brief summary of each follows:

a) Base Band
A base band video signal modulates the intensity of the light source projected along the fibre. An optical receiver detects variation in light intensity and recreates the video signal. Baseband is particularly suited for data transmission. It requires a separate cable for each video camera utilized.

b) Vestigal Amplitude Modulation
Video signals are modulated and transmitted at different frequencies onto an optical fibre. The frequencies are detected by a receiver and separated by a filter. Up to 3 video signals can be transmitted and received on a single optical fibre. Repeaters are required.

Exhibit 15b

ADVANTAGES AND DISADVANTAGES OF TWISTED PAIR CABLE

Advantages

- Has lower cost than other mediums in smaller, less sophisticated systems
- Has less sophisticated communications equipment
- Is more reliable than other mediums
- Requires less sophisticated maintenance personnel than other communications mediums

Disadvantages

- Does not readily support CCTV monitoring
- Increases cost of system in proportion to the number of channels required by increasing the number of cable pairs
- Limits expansion of system (determined by the number of spare pairs installed).

Exhibit 15c

ADVANTAGES AND DISADVANTAGES OF COAXIAL CABLE

Advantages

- Will support the most sophisticated system and CCTV monitoring
- Is reliable
- Can provide system redundancy
- Can expand system easily until the maximum capacity of the cable is reached.

Disadvantages

- Is more costly due to the need for line amplifiers
- Requires highly skilled maintenance personnel
- Is more susceptible to damage due to mishandling

Exhibit 15d

ADVANTAGES AND DISADVANTAGES OF FIBRE OPTIC CABLE

Advantages

- Supports the most sophisticated systems and CCTV monitoring readily
- Provides complete immunity from electromagnetic interference
- Is free from ground loop problems
- Is less expensive than coaxial cable systems
- Is reliable & virtually tamper proof
- Has more flexibility to increase data transmission than twisted pair — therefore more easily expandable

Disadvantages

- Is more costly than twisted pair systems due to the need for repeaters
- Is difficult to join or terminate
- Utilizes sophisticated transmission and reception equipment requiring highly skilled maintenance personnel
- Is not as readily expandable for a CCTV system as coaxial cable.
- Is not flexible: must be carefully installed to prevent fibre from being crushed
- There is a lack of standardization in fibre optic industry

Exhibit 15e

ADVANTAGES AND DISADVANTAGES OF RADIO TRANSMISSION

Advantages

- Supports the most sophisticated systems and CCTV monitoring
- Reduces need for excavation during construction and exposure of cable system to damage
- Is readily expandable — providing channels are available in the area
- Can transmit information great distances cheaply

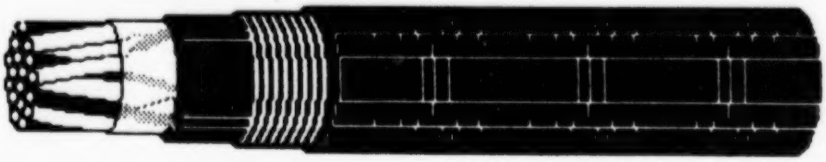
Disadvantages

- Is subject to signal disturbances due to atmospheric conditions and new construction
- Has high receiver and transmitter cost
- Requires specialized maintenance personnel.

Exhibit 15f
TWISTED PAIR CABLE

Direct Earth Burial
Signal-Communications Cable

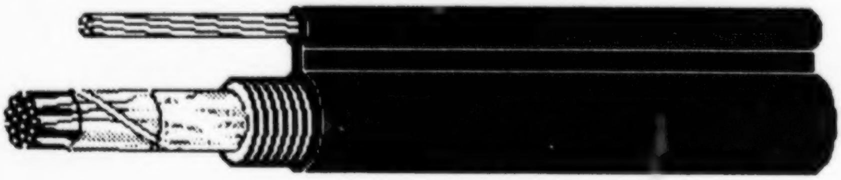
IMSA Spec. 20-6-1962/67/73/82
IMSA Spec. 19-6-1962/67/73/82



Conductors	- Twisted Pairs
Shield	- Copper tape between jackets
Jackets	- Inner - Polyethylene - Outer - IMSA 20-6 Black Polyethylene (PE) IMSA 19-6 Polyvinyl Chloride (PVC)

Figure "8" Self-Supporting Aerial
Signal — Communications Cable

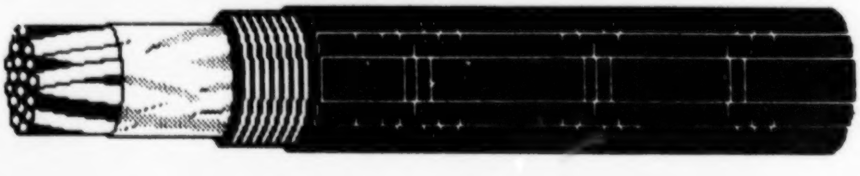
IMSA Spec. 20-4-1962/67/73/82
IMSA Spec. 19-4-1962/67/73/82



Conductors	- Twisted Pairs	
Shield	- Copper tape under jacket	
Jacket	- IMSA 20-4 Black Polyethylene	(PE)
	IMSA 19-4 Polyvinyl Chloride	(PVC)

Aerial (Lashed) & Duct
Signal-Communications Cable

IMSA Spec. 20-2-1962/67/73/82
IMSA Spec. 19-2-1962/67/73/82



Conductors	- Twisted Pairs	
Shield	- Copper tape under jacket	
Jacket	- IMSA 20-2 Black Polyethylene	(PE)
	- IMSA 19-2 Polyvinyl Chloride	(PVC)

Exhibit 15g

COAXIAL CABLE

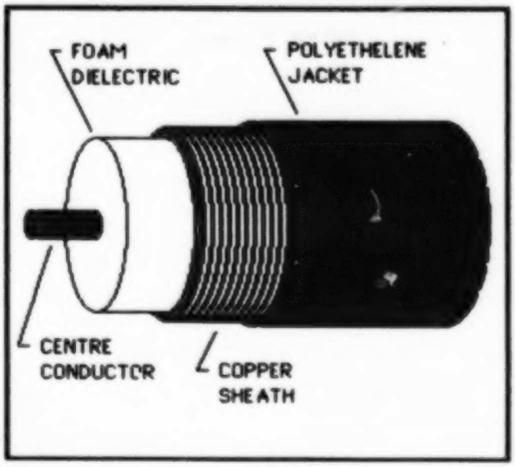
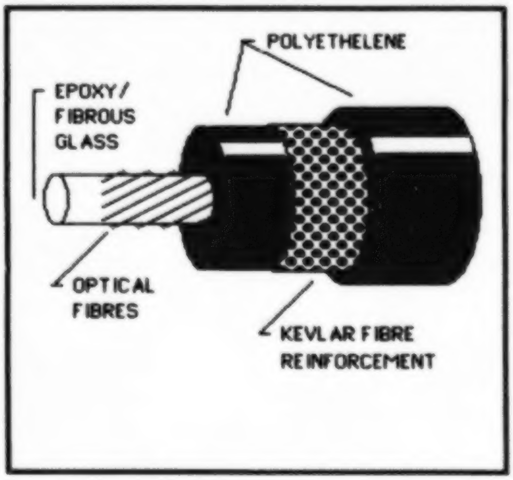


Exhibit 15h

FIBRE OPTIC CABLE



c) Double Side Band Amplitude Modulation
This type is similar to vestigal A.M. but it uses a frequency converter to split the signal at the receiver. Up to 3 video signals can be carried on a single fibre. Repeaters are required.

d) Multichannel Frequency Modulation
The video signal is modulated into a set frequency band width and transmitted on a fibre. A splitter at the optical receiver converts several signals into the individual signals. Up to five video channels can be carried on an individual fibre. Repeaters must be used.

e) Time Division Multiplexing
The time available for data transmission is divided into very short time intervals and a time slot is allocated to each receiver and transmitter on the fibre. This type is suitable for data transmission only. Repeaters are required.

f) Wavelength Multiplexing
For this type of fibre optics system, an optical combiner converts video signals into differing wavelength frequencies. Up to three video signals may be transmitted on an individual fibre. Repeaters are not required.

Leased System

A major consideration in selecting the communications medium for a freeway management system is whether:

- to utilize a leased system from the telephone or cable T.V. utility company; or
- to install an agency owned system.

Cost and time frame to implement the communications system are prime concerns. The major factors which affect the cost of a leased line system are:

- availability of spare channels in the vicinity;
- distances from existing telephone service to the field equipment cabinets;
- number of drops required;
- amount of new construction required;
- number of central offices and jurisdictions involved; and
- cost for the local power structure.

The reliability of the existing leased system should be examined in detail. It should also be recognized that future reliability may not be under the direct control of the freeway management system operating agency.

Exhibit 15i

ADVANTAGES AND DISADVANTAGES OF FREQUENCY DIVISION MULTIPLEXING

Advantages

- Is less sensitive to noise
- Has simple maintenance requirements
- Is reliable with good performance
- Has moderate cost

Disadvantages

- Requires substantial space for modular channels
- Requires a channel for each function.

Exhibit 15j

ADVANTAGES AND DISADVANTAGES OF TIME DIVISION MULTIPLEXING

Advantages

- Is reliable with good performance
- Is easily expandable
- Is easily adaptable to use with computer equipment
- Requires less space to house control equipment

Disadvantages

- Is most expensive of the three twisted pair methods
- Is sensitive to noise
- Is more difficult to maintain than other methods.

Exhibit 15k

ADVANTAGES AND DISADVANTAGES OF DIRECT CURRENT SWITCHING

Advantages

- Is less sensitive to noise
- Is reliable with good performance
- Has low to moderate cost

Disadvantages

- Has very limited functional ability
- Has high central space requirements
- Is not readily expandable
- Has poor availability of equipment

Agency Owned System

In examining the option of installing a communications system that is owned entirely by the government agency, detailed communications cost estimate comparisons should be made. This should include an examination of the initial capital cost, the annual operating costs, and the total equivalent cost. These costs should be examined for each of the communication medium types considered for use.

Just as for the leased system option, the reliability of the communications equipment and the medium provided should be fully evaluated. In certain locations in the United States, for example, it was determined that the leased channel reliability was unpredictable because it was dependent upon telephone company activities (which can cause outages or electrical noise on the lines).

In considering the maintainability of leased versus owned channels, it should be recognized that leased channels are maintained by the telephone company, which may result in longer outages and lower reliability than a service that is performed by an independent competitive organization. In examining the flexibility of leased versus agency owned communications systems, it should be recognized that leased channels are available at most locations, but if new facilities must be built by the utility company, delays in implementation could result.

All of the above factors must be fully considered so that a communications system — which will best meet the needs of the particular location and offer the control features desired — can be selected.

Exhibit 15l

ADVANTAGES AND DISADVANTAGES
OF
LEASED SYSTEM

Advantages

- Can reduce capital construction costs and speed implementation
- Reduces maintenance requirements at FMS operating agency

Disadvantages

- Is subject to increases in tariffs
- Does not provide the direct control at the FMS operating agency, which in turn may limit the system reliability.

Exhibit 15m

ADVANTAGES AND DISADVANTAGES
OF
AGENCY OWNED SYSTEM

Advantages

- Assigns system operations under the direct control of the operating agency
- Provides greater built-in reliability.

Disadvantages

- Has high initial capital construction cost
- Requires continual maintenance by agency.

15.3
Equipment

The primary components of the communications system are:

1) the field communications transmitter and receiver, i.e. Remote Communications Unit (RCU);
2) the central office communications transmitter and receiver, i.e. Central Communications Unit (CCU); and
3) the transmission medium.

The RCU is usually housed in a field cabinet which also serves to house other system equipment such as the surveillance detectors, ramp metering controller or variable message sign controller. The RCU transmits and receives data on the transmission medium and in some cases also preprocesses data from the various other elements of the freeway management system prior to forming a signal for transmission.

The CCU consists of various modular elements housed in a rack that receive and transmit data from the field and convert those signals into data that the central computer can accept. In the case of CCTV, the CCU receives the video signal and modifies it for use at the central TV monitors.

A radio communications system utilizes a radio transmitter and receiver at each field location coupled with an antenna to send and receive information to the central facility. At the facility, a tall antenna sends and receives radio signals and passes the information to the central radio transmitting and receiving station.

The other three communications mediums consist of a cable connecting the central facility to each field location. The cable may be placed underground by direct burial or in a conduit, or may be placed on existing utility poles. The most effective means of construction is often to mix the three types of placement based on potential exposure to damage and cost of the installation.

Aerial cable installation is often the easiest and least costly. The cable is supported between utility poles by a messenger strand of galvanized wire cable. The cable can be made integrally with the messenger strand, commonly refered to as figure eight cable, or attached to the messenger by a stainless steel wire lashing.

Direct burial cable is provided with an extra layer of polyethylene insulation and is laid directly in a trench in the ground. Direct burial cable is particularly suited to areas adjacent to a freeway where the rights-of-way are controlled by highway agencies and there is little chance of excavation by utilities and developers that might disturb the cable.

Installation of cable in conduit is the most expensive of the three installation methods. While the cable is slightly cheaper than the direct burial cable, the cost of the conduit can range from $6/m to $30/m depending on the size and material selected. Galvanized steel offers the best protection with fibre glass second and PVC third. With the installation of conduit there is also a necessity to install additional pullboxes to facilitate the placement and maintenance of the cable.

With both direct burial cable and cable in conduit,a major cost is the excavation and restoration of the trench and surface area. In the case of undeveloped land the cost may be only a few dollars a metre but can range to $100-$150/m along sidewalks in urban areas and up to $300/m across concrete pavement areas.

Coaxial cable and fibre optic cable require specialized equipment placed between the RCU and the CCU in order that the data be transmitted over the required distances. Connectors are required to terminate the cable and interface the cable with equipment with which it is connected. Fibre optic cable requires repeaters which receive a signal and retransmit it while coaxial cable requires amplifiers to boost the signal and carry it along.

15.4 Cost Components

The costs of a communications system is dependent on the location of the particular project and the amount of data that the freeway management system requires to be transmitted. Thus, conclusions cannot be drawn from generalized trade-off studies or a 'typical case' trade-off study. However, in order to assist the engineers in preliminary assessment of alternative communications systems, some very approximate costs of the various elements are presented in Exhibit 15n.

Exhibit 15n
COMMUNICATIONS ELEMENTS
— Approximate Costs —

MEDIUM COSTS	$
Twisted Pair Cable	
25 Pair Cable (installed)	4/m
TDM RCU	800-1 000/unit
FDM RCU	500/unit
DCS RCU	200-700/unit
Coaxial Cable	
Cable	5/m
RCU	2000/unit
CCU (for up to 90 RCU)	60 000
Line Amplifiers	2 000/unit
Line Amp. Power Supply	500/unit
Fibre Optic Cable	
Cable	5/m
RCU	2 500/unit
CCU	10 000
Radio	
RCU	5 000-6 000/unit
INSTALLATION COSTS	
Conduit	
3 inch PVC	15/m
3 inch Galvanized Steel	30/m
Excavation & Restoration	
Undeveloped	15/m
Concrete Sidewalk	100/m
Asphalt Roadway	215/m
Concrete Roadway	280/m
Jack Conduit	200/m
Pullboxes	500/unit
Installation on Messenger	6-13/m

15.5 Application Criteria

The various possible configurations of communications systems offer many solutions to the communications task. The system chosen for a particular project represents the largest portion of capital and operating cost of the system and the acceptability of a given system is greatly influenced by conditions at the project location. A summary of the applicability of the alternative mediums is presented in Exhibit 15o.

Exhibit 15o
APPLICATION CRITERIA FOR COMMUNICATIONS MEDIUMS

APPLICATION CRITERIA	ALTERNATIVE SYSTEMS				
	Leased	Agency Owned			
		Twisted Pair	Coaxial	Fibre Optics	Radio
Communications Capability					
• Transmits field data to central	✓	✓	✓	✓	✓
• Transmits central instructions to field	✓	✓	✓	✓	✓
• Will support TV monitoring	✓		✓	✓	✓
• Is not susceptible to interference			✓	✓	
• Can provide redundancy			✓		
Installation Features					
• Minimizes capital construction	✓				✓
• Requires special handling of cable				✓	
• Is suitable for aerial installation		✓	✓	✓	
• Is suitable for direct burial		✓	✓	✓	
Operating Characteristics					
• Requires specialized skills			✓	✓	✓
• Is reliable	✓	✓	✓	✓	✓
• Requires repeaters or amplifiers			✓	✓	

16.
CENTRALIZED COMPUTER CONTROL FACILITIES

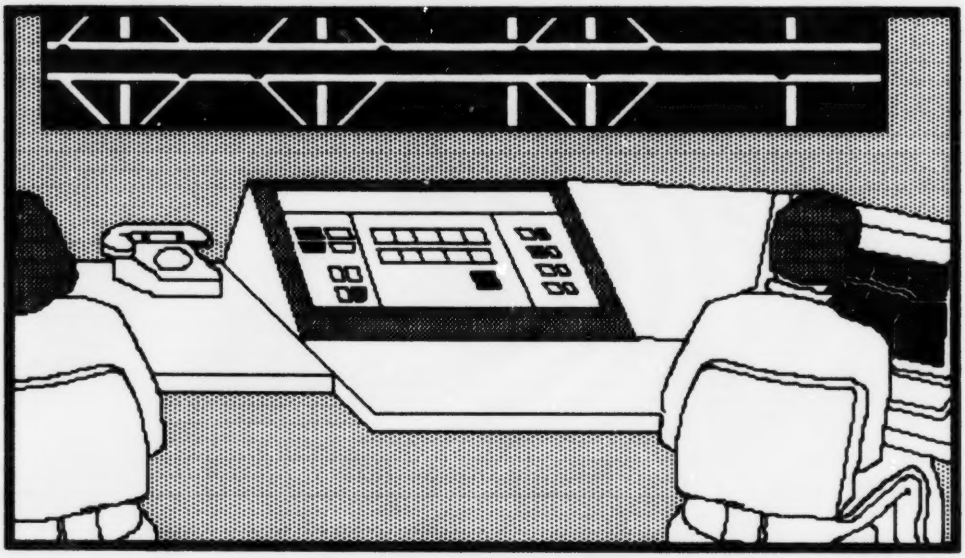


Exhibit 16a

16.1 Concept

Centralized computer control facilities perform the major function of receiving and analyzing all of the data obtained from the various field elements, as well as transmitting directions and commands back to each of the elements located at the specific field sites. Depending on the size of the freeway management system, and on the number of elements that comprise the various subsystems, the actual functions performed at the computer centre will vary extensively.

In comparison to parts of the body: the incident detection system is similar to the sensory senses of the human body; the communications system is similar to the blood circulation system; and the control centre can be related to the body functions of both the heart and the brain. The major functions for the freeway management system are performed at the control centre with the appropriate interaction with human beings from the various participating agencies.

16.2 Techniques

The computer is the main hardware equipment contained within the control centre. The main computer performs the following functions:

- Receives data from the various field elements
- Transmits data and commands to the field equipment
- Receives operator commands inputted at the control centre
- Analyzes and processes data received, in order to determine appropriate control strategies and measures
- Prints out specific data needed for immediate examination by the operators
- Provides records of data
- Interfaces with all peripheral equipment.

Agency Co-ordination

The co-operation and participation of all the involved agencies within the limits of a freeway management project should be enlisted in the earliest stages of the project. It should be maintained from the early planning stages and continued throughout the operation of the project. These agencies should include:

a) the provincial Ministry of Transportation & Communications (or the corresponding two ministries/departments, if separate)
b) the Traffic & Roads Departments (and, in some instances, the Transportation Planning Departments) of the
   — regional municipality(ies)
   — local municipalities
c) the regional and local transit operators
d) the Traffic Enforcement Departments of the provincial and local police
e) other necessary agencies (particularly in the case of implementing HOV preferential measures):
   — Parking Authorities
   — Tow Truck Operators
   — Car and Van Pool Associations
   — Intercity Bus Associations
   — Taxi Associations
   — Chambers of Commerce
   — Automobile Clubs
   — Ministries of Environment and Energy
   — etc.
f) Transportation Development Centre, and the Surface Administration of Transport Canada (for demonstration projects).

Of course, only selected essential agencies would actually participate in the day-to-day operation of the freeway management system and its centralized control facility.

In several freeway management projects in the United States, multiple agencies have participated in the day-to-day management and operation of the control centre. An initial team established in Los Angeles, California included members of the California Highway Patrol, the maintenance and traffic engineering sections of the State Department of Transportation, and tow truck services.

Staffing for most freeway management projects has been provided by personnel from the responsible operating agency; however, the maintenance responsibilities have been shared between the agency and separate maintenance contractors. Recently, a contracting approach has been adopted in many maintenance and operating situations. On large projects, consideration should be given to utilizing the contract operations concept to engage firms that have expertise in traffic engineering, traffic surveillance and control, computer technology and other related specialty areas.

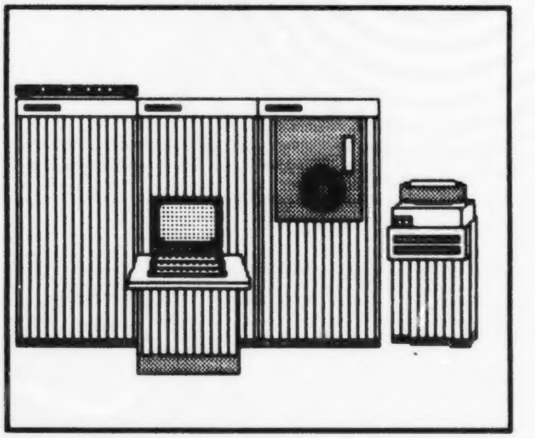
16.3 Equipment

A centralized computer control facility contains the following equipment:

- computer
- computer peripherals: CRT video display, printer, mass storage device
- control consoles: computer, variable message signs, ramp metering
- display map(s)
- video surveillance and graphics displays
- monitors for emergency telephones, CB radio, HAR
- cassette tape equipment (with prerecorded messages)
- special printer for transmitting traffic status reports to news media.

The computer receives information from the field and transmits to the field via the central communiations unit (CCU) which is housed at the central control centre (Exhibit 16b). The CCU is part of the communications sub-system. The different types of communications modes are discussed in this report in the chapter on communications.

Exhibit 16b
COMPUTER & PERIPHERALS



The computer is actually a two component system. The first component is the computer itself and the second is the software program with algorithms which instruct the computer to perform its various tasks such as data collection, analyses, reporting, and sub-system control.

The computer selection for the central control centre must be based on the size of the system to be controlled and the means by which field data is collected. These factors will influence the size of the computer memory, and the speed at which the computer works. In some systems, two or three small computers are coupled together and the tasks of managing the system are divided between the different computers. This method provides redundancy and backup if one of the computers fails and may prove more effective than utilizing one large computer.

The computer interfaces with the operators of the central control facility through its various peripheral devices. The peripheral devices include:

1. **A CRT (cathode ray tube) video display with a keyboard.** This device allows the user to communicate with the computer for the purpose of changing programs. The CRT can also present information from the computer to the user (Exhibit 16c).
2. **Mass storage device.** The various devices that can accomplish this task include:
   - hard disk
   - floppy disk
   - magnetic tape drive

   These devices keep system records in a compact form (Exhibit 16d).
3. **Printers.** The printers provide the system user with a hard copy print-out of system reports. There are several devices that can perform these tasks:
   - high speed line printer (Exhibit 16e)
   - teleprinter (which can also be used to input data).

Exhibit 16c
CATHODE RAY TUBE (CRT)

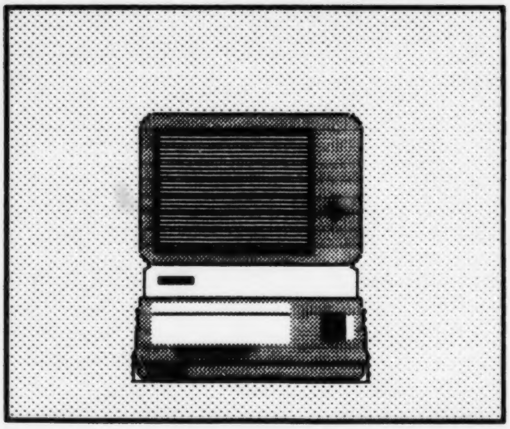


Exhibit 16d
MAGNETIC TAPE DRIVE

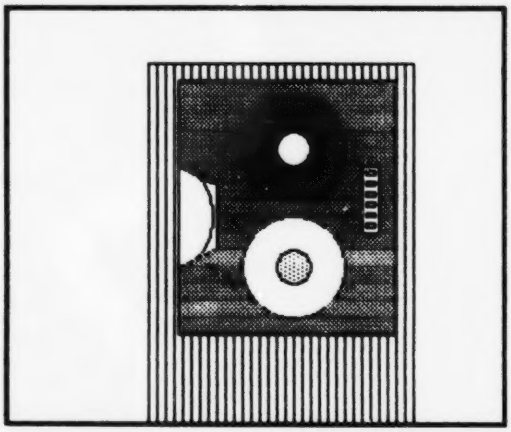
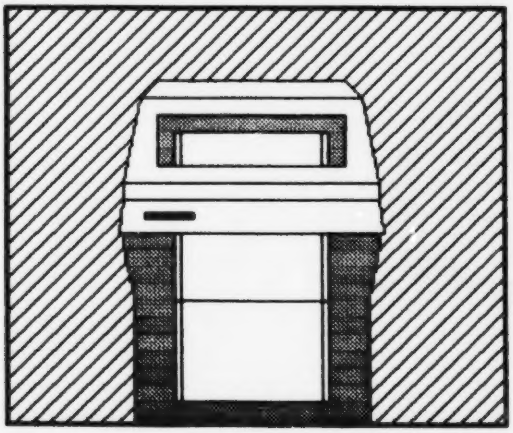
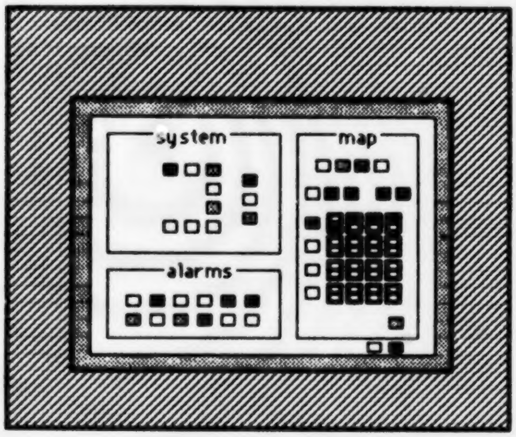


Exhibit 16e
HIGH SPEED LINE PRINTER



The system control console is used by the system operators to command various subsystems. From this console the operator can perform such tasks as setting the metering rate at a ramp meter location, implementing a variable message sign message change or implementing a traffic signal pattern change. The console is usually specially constructed to the specifications of the system to be controlled. (Exhibit 16f).

Exhibit 16f
CONTROL CONSOLE



The system display map presents the operators with a visual status of system conditions. The display map is also used as a public relations device that can be understood by visitors. The map usually shows all system controllers (detectors, ramp meters, etc.) with different colour lights that present their status. The detector location lights indicate the level of traffic congestion at that detector location (green = no congestion; yellow = build up of congestion; red=congestion). (See Exhibit 16g).

Video graphics are also used to present a display on a CRT in place of or in addition to a separate display map (Exhibit 16h).

Exhibit 16g
SYSTEM DISPLAY MAP

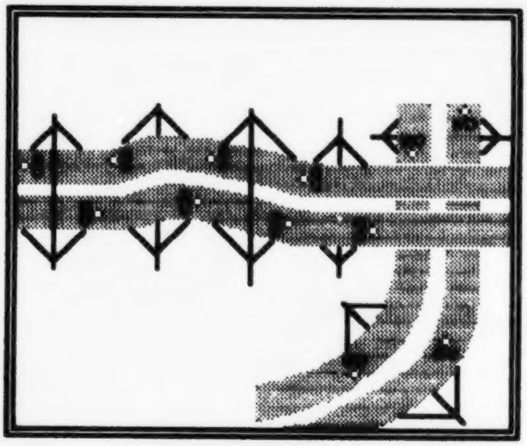
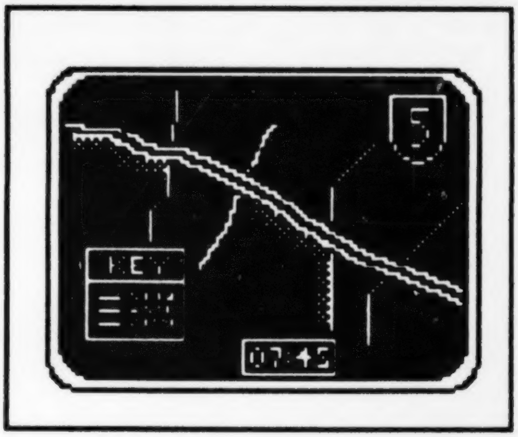


Exhibit 16h
VIDEO GRAPHIC DISPLAY



16.4 Cost Components

In order to assist the engineer in assessing the costs of a central control room, typical costs are presented in Exhibit 16i. The actual costs will depend on the size of the system to be implemented. Communications costs outside the building and within the control room are not included in Exhibit 16i.

Exhibit 16i
CENTRAL CONTROL ROOM COSTS

ELEMENT	COST ($)
Central processing unit	70 000-150 000
CRT	12 000
Line printer	4 000
Disk drive	12 500
Magnetic tape drive	10 000
Map display	75 000-125 000
Central console	5 000-20 000

16.5 Application Criteria

The selection of equipment for a centralized computer control room, will depend heavily on the site specific needs of the particular traffic management system and its various subsystems. A summary of the functions which will need to be performed by the various equipment in the centralized computer control room, depending on the system features and requirements, is presented in Exhibit 16j.

Exhibit 16j
APPLICATION CRITERIA
FOR
CENTRALIZED CONTROL EQUIPMENT

	REQUIRED CONTROL EQUIPMENT											
					System Monitors							
APPLICATION CRITERIA	Computer	CRT	Printer	Control Console	Map Display	Video Graphics Display	VMS	HAR	Remote CB Radio	Ramp Signals	Traffic Signals	CCTV
System Size/Function (Examples)												
• Small surveillance system for traffic monitoring & recording	✓		✓	✓								
• Highway advisory radio system			✓	✓				✓				
• Surveillance & control system with VMS, HAR, ramp metering, incident management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Status Checks												
• Traffic flow	✓	✓	✓		✓	✓						✓
• Incidents	✓	✓	✓						✓			
• Incident verification	✓											✓
• Signals	✓	✓	✓		✓	✓					✓	
• Ramp meters	✓	✓	✓		✓	✓				✓		
• Diversion/Alternative routing	✓	✓	✓				✓	✓				
• Equipment Failure	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓

17.
IMPLEMENTATION STEPS

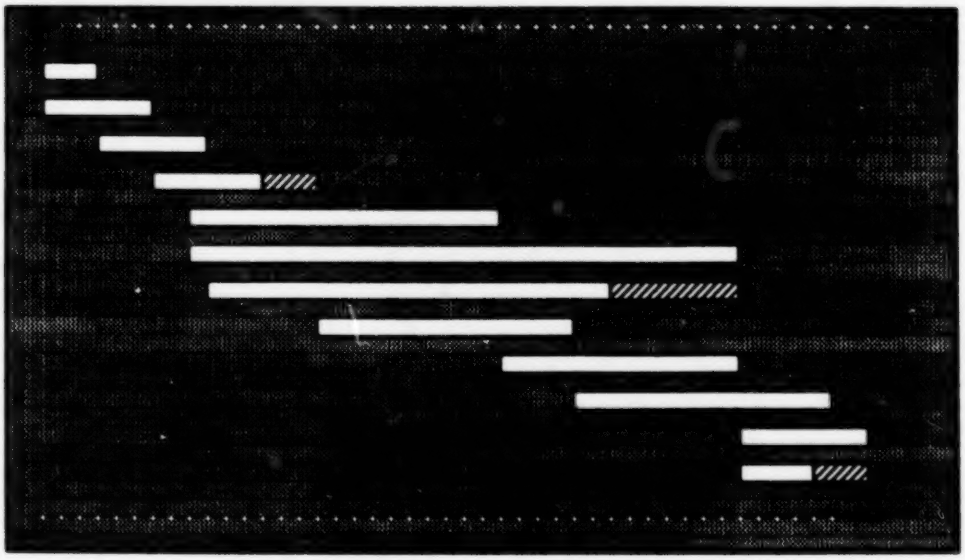


Exhibit 17a

17.1
Project Phases

The implementation of a typical freeway management system is a complex undertaking which consists of the following five primary steps:

- identification of problems & objectives
- evaluation of feasibility
- design & construction
- integration & operation & maintenance
- monitoring & evaluation & enhancements.

The development and operational phases for a freeway management project — with a short description of the main activities — are presented in more detail in Exhibit 17b.

During the feasibility phase — an overall freeway management plan, covering the entire metropolitan area, should be developed and evaluated. This will facilitate identification of the best staging plan and preliminary optimization of the timing for these stages. It can prevent serious, costly problems rising later when the first stage is to be expanded or when the freeway management system is to be connected with the area traffic control.

In setting up the stages, many factors must be considered — to avoid starting more at once than is practical and achievable:

- technical constraints: system continuity; physical restrictions in the plant; components and their limitations;...
- technical opportunities: synergistic effect through complementary incentive/disincentive measures; 'stringing' of measures; near-term technology advances;...
- financial constraints: money securable in time from all participants; competing priorities, different within each agency;...
- jurisdictional constraints: resistance to ramp control strategies; resistance to alternative routes; concerns over revenue & cost sharing on regional/local transit;...
- user support: immediate, documentable benefits; HOV preference over SOVs justifiable & reasoned; careful timing of incentives vs. disincentives;...

In selecting specific management approaches and detection/verification/response and control techniques for inclusion in each stage, the planners and traffic engineers will need to:

- be aware of major issues which are going to influence the decision making process (eg. as above & Exhibit 3b)

- select priority goals and objectives (eg. from Exhibit 2b & 2f) for the overall project and its stages — while recognizing the constraints and opportunities of each implementation site (eg. Exhibit 3b)
- seek maximum return on investment through innovative packaging and stringing of complementary management measures (eg. Exhibit 3f)
- recognize the special thrusts of each of the development phases of the project (Exhibit 17b); and
- seek the participation of all relevant agencies.

17.2
Participation

In order to assure that a project may progress as smoothly as possible at each phase of its development, it will be important to gain the participation and cooperation of all agencies and groups which have a direct interest in the freeway management system. This involvement should begin at the earliest phases of development, already during problem identification — and continue throughout the project, including its monitoring, evaluation and enhancement phases.

Depending upon whether the project is located in a metropolitan or rural area, the number of involved agencies and groups will vary considerably. These can include specific research, planning, design and operations units within several ministries or departments of the provincial and federal governments and within two levels of municipal government — as well as numerous private enterprises: consultants, carriers and various associations. A steering committee, consisting of representatives of those agencies and groups, is usually set up to oversee the project management and to provide a forum for consultation and coordination throughout the project.

The agencies and groups potentially involved in freeway management systems, in Canada and the United States, are listed in Exhibits 17c and 17d.

Exhibit 17b

DEVELOPMENT & OPERATIONAL PHASES OF FREEWAY MANAGEMENT SYSTEMS

PROJECT PHASE	DESCRIPTION
1. Awareness and Identification of Problem	Recognition of problems, and preliminary identification of possible freeway management system approaches
2. Planning Applicability Study	Examination of specific freeway management techniques which may be implemented to address the problems—based upon site specific conditions
3. Feasibility Study	In-depth examination of alternative techniques, and recommendation of a preferred system of techniques for implementation
4. Design of Plans, Specifications and Estimates	Preparation and design of plans and specifications, and development of cost estimates for the selected system
5. Bid Selection	Determination of qualifications of contractors, invitation of bids, and selection of winning bid
6. Construction	Engagement of qualified construction firm and equipment suppliers, and installation of all system components
7. Construction Inspection	Supervision of the contractor, and inspection of quality of construction and type of equipment to assure that all work and installed equipment meet their specifications
8. Consultant Selection	Determination of the use of Request for Proposals, or a designation process, to select a consultant—if necessary—for the following phases: — system integration & acceptance testing — system operation — system maintenance — system evaluation — system enhancements
9. System Integration and Acceptance Testing	Preparation of system software programs, and testing of acceptance performance to assure full operation of the total system and all of its components
10. System Operation	Establishment of management structure and procedures, and staffing of the day-to-day management and control of the system
11. System Maintenance	Provision of necessary equipment and staffing to maintain all components in the field and at the control centre
12. System Evaluation	Development and selection of specific measures of effectiveness (MOEs), carrying out of continuous or periodic monitoring, and determination of the performance of the system and its elements
13. System Enhancements	Identification of system deficiencies, and development and selection of additional management applications and techniques which will support and enhance the overall operation of the system.

Exhibit 17c

AGENCIES AND GROUPS INVOLVED IN FREEWAY MANAGEMENT SYSTEMS
— CANADA —

FEDERAL GOVERNMENT

- Transport Canada
  - — Transportation Development Centre
  - — Surface Policy Planning & Urban Prgs
  - — Highway Transportation
  - — Road and Motor Vehicle Traffic Safety
- Energy, Mines and Resources Canada
  - — Transportation Energy Division
- Environment Canada
  - — Environmental Protection Service
  - — Parks Canada
- Indian & Northern Affairs Canada
  - — Technical Services & Contracts Branch

PROVINCIAL GOVERNMENT

- Ministry of Transportation and Communications; or
- Department of Highways and Transportation

  H.Q./Regional/District Offices
  - — Research and Development
  - — Transportation Energy
  - — Urban Transportation Planning
  - — Transit Planning
  - — Traffic Management and Engineering
  - — Highway Programming
  - — Communications
  - — Engineering and Right of Way
  - — Contract Management
  - — Construction
  - — Maintenance Operations
  - — Safety
- Provincial Police (Solicitor General)
- Ministries of Environment and Energy

MUNICIPAL GOVERNMENTS
(Regional & Local)

- Traffic and Roads Department(s)
- Transportation Planning Department
- Transit Operator(s)
- Parking Authority
- Municipal Police (& RCMP)

PRIVATE SECTOR

- Tow Truck Operators
- Car and Van Pool Associations
- Taxi Association(s)
- Intercity Bus Association
- Provincial (& Canadian) Trucking Assocation
- Parking Facility Operators
- Automobile Clubs
- Chamber(s) of Commerce
- News Media
- Contractors — Construction
  - — Maintenance
- Consultants — Research
  - — Planning
  - — Design
  - — Operations & Mgt
- others (as req'd)

Exhibit 17d

AGENCIES AND GROUPS INVOLVED IN FREEWAY MANAGEMENT SYSTEMS
— UNITED STATES —

FEDERAL GOVERNMENT

- Federal Highway Administration
  - — Office of Traffic Operations
    - — Traffic Engineering Division
    - — Signals, Communic. and Lighting Div.
    - — ...
  - — Office of Safety and Traffic Operations Research and Development
    - — Urban Traffic Management Division
    - — Safety and Design Division
    - — ...
  - — Regional Office
  - — District Office
- Urban Mass Transportation Administration
  - — Office of Service and Mgt Demonstrations
  - — ...

PRIVATE SECTOR

- Consultants — Systems integrator
  - — Evaluation
  - — Planning & design
  - — Operations
- Contractors — Construction
  - — Maintenance
- Francise Tow Truck Operators
- others (as req'd)

STATE AND LOCAL GOVERNMENTS

- State Department of Transportation
  - — Regional Office and Main Office
- City Department of Transportation
- County Department of Public Works
- State Parks and Recreation Commission
- State Office of General Services
- Police — State
  - — County
  - — City
  - — Village
- Local Metropolitan Planning Organization
- Regional State DOT Groups
  - — Traffic and Safety Group
  - — Maintenance Group
  - — Planning Group
  - — Design Group
  - — Oil Spills Group
  - — Construction Group
  - — Operating Group

17.3 Necessary Support Programs

The implementation of innovative transportation solutions is frequently hindered by certain professional reluctance, organizational inertia and political indifference. In the case of freeway management systems, there are many reasons for this:

- freeway management systems can, in strictly technical terms, be much more complicated to plan and implement than new road construction;
- freeway management systems include modern planning and analytical concepts, with which many transportation planners and traffic engineers are unfamiliar or uncomfortable — eg:
    - 'demand *management*' (not just fine tuning the supply or 'improving traffic flow')
    - preferential & exclusive treatment of high occupancy vehicles (not treating all vehicles alike)
    - 'person throughput capability' (not just 'vehicle capacity') — calculated for a *corridor* of parallel facilities (not just for the freeway), with full utilization of throughput buffers provided by different peak lengths on the parallel facilities
    - alternative work schedules offered by employers to enable use of peak shoulder capacity on both transit and the road system
    - etc
- the experience of senior staff in transportation planning agencies is typically concentrated on the 1960's/early 70's-type route feasibility studies and design of new roadways;
- freeway management systems are perceived to lack the 'political opening grandeur' of new freeways.

The reluctance to plunge into something new and more complicated is perhaps quite understandable. The selection of innovative TSM alternatives still requires, in many agencies, more careful justification and nurturing than proposing conventional new construction. Many potentially excellent, cost-effective proposals have faltered — and even been removed from the system after their implementation — due to lack of carefully planned support programs. There is a need to 'sell' these projects: to make sure that sound technical evidence on their financial, transportation access and safety, energy and environmental benefits is developed — and then fully transmitted to the decision makers. Several support plans are required to ensure the successful development, installation and operation of any freeway management project:

- *marketing plan* — to enlist the support of management personnel and political decision makers
- *public relations plan* — to communicate with news media, freeway corridor users and the public-at-large
- *staging plan* — to split the project into technically, financially and politically manageable stages
- *funding plan* — to budget and obtain sufficient funds from all contributing agencies for each stage in a timely fashion
- *educational plan* — to increase the expertise of agency staff and the knowledge of others involved in the project
- *operating & management plan* — to provide staff with step-by-step approach for the day-to-day operation and maintenance of the system and its components
- *research plan* — to monitor and advance the state-of-the-art in freeway management techniques and devices, and to establish contacts with managers of other projects in order to share experiences and avoid 're-inventing the wheel'
- *monitoring & evaluation & enhancement plan* — to monitor the performance of the adopted strategies and elements, to measure the cost-effectiveness and efficiency of the system, and to identify necessary improvements.

18.

EVALUATION OF FREEWAY MANAGEMENT SYSTEMS

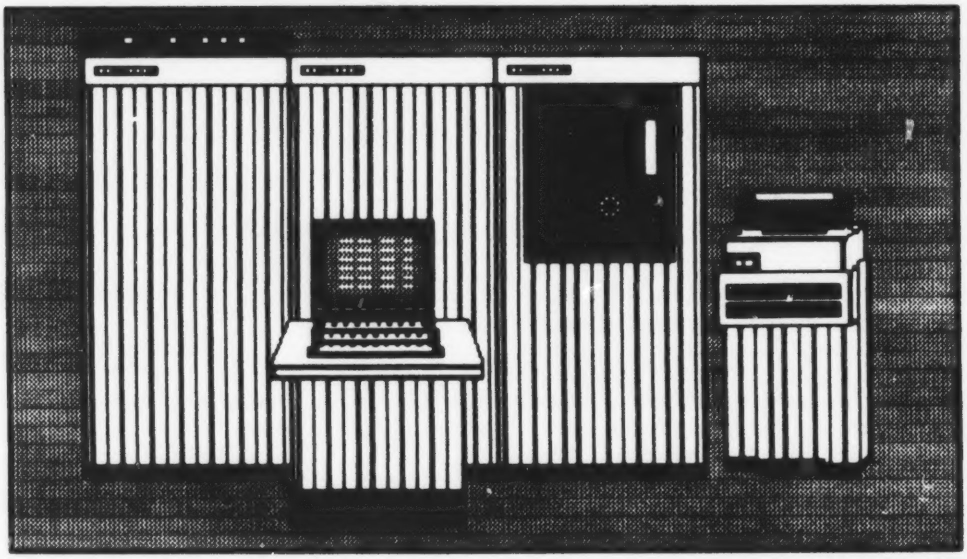


Exhibit 18a

18.1

Evaluation Techniques

There are several techniques, some of which have been covered by this report, that are available for the evaluation of freeway management system alternatives:

1. *Advantages/Disadvantages charts* — which present some of the key advantages and disadvantages of alternative techniques (included in Chapters 5-11 & 14-15);
2. *Application Criteria charts* — which present the yes/no applicability (or preference) of each alternative technique against specific criteria or situation (included in Chapters 4-11 & 13-16);
3. *Performance Rating charts* — which are designed for rating the anticipated/speculated performance of each competing freeway management technique by using simplified Low, Medium and High scores (included in Chapter 12/Exhibit 12f);
4. *Linear Scoring Function (LSF) charts* — which compare alternatives on a point system, where for each alternative an initial score [from 1 (=lowest) to 10 (=highest)] against each evaluation factor is multiplied by the relative weight given to that factor (arrived at, in comparison to other evaluation factors, by an interdisciplinary delphi-type process); the best alternative is the one which accumulates the most total points;
5. *Measures of Effectiveness (MOE) tables and figures* — which display some of the key measures and units which should be used to monitor the performance of an implemented system (Section 18.2); to the extent that reasonable base assumptions

can be made, and impacts estimated, some of these MOEs can also be used in the evaluation of competing alternatives; and

6. *Cost-benefit analysis* — which compares the economic efficiency of alternatives on the basis of total transportation cost (capital, operating, maintenance cost and salvage value of road & transit systems + all vehicles), using such criteria as :
   - — equivalent uniform annual cost
   - — present worth of cost
   - — equivalent uniform annual net return
   - — net present value
   - — benefit/cost ratio
   - — financial rate of return.

Techniques 3, 4 and 5 are all variations of 'cost-effectiveness' analysis which is the companion economic analysis technique for the cost-benefit technique. Effectiveness analysis is based on the assumption that although the implementation costs (of a freeway management system) are measured in clear monetary terms, the effectiveness of these costs in reaching desirable social and economic goals (or the benefits and adverse consequences) can only be described in qualitative terms. With this technique, an attempt is made to trace out the social and welfare economic effects (from a transportation investment) on the road users/non-users and the community-at-large as well as the ecological effects on the balance of nature. In a comprehensive analysis, these include the development, distribution and spill-over effects of the investment.

In a significant refinement of both the cost-benefit and the cost-effectiveness analysis technique, the transportation investments, carefully split into separately implementable stages, are evaluated by using incremental analysis (typically part of an engineering value analysis): ie. by developing incremental B/C ratios or LSF ratings separately for each of the stages. The incremental analysis techniques are particularly useful when evaluating complex, large scale transportation investments in mature metropolitan areas — where freeway management system stages might constitute the first stages of an improvement program. When rigorously applied, these analysis techniques frequently highlight the great advantages of TSM-type investments over large, new capacity investments. The incremental B/C ratios, and the accumulated LSF points, are usually superior for the freeway management system type investments.

Which one of the above analytical techniques or decision-making tools should be used, depends on whether a preliminary assessment or final evaluation is required, on the level of detail and reliability of available data and on the resources available. The use of any of the above techniques, whether applied for 'back-of-the-envelope' quick assessments or for 'recycled-process-model' type detail evaluations, will include large doses of professional and personal judgement — which is so dependent on each individual's professional training and experience, personal preferences, current 'location' (of residence and/or work place vis-a-vis the facility), and current 'situation' (his agency's official *and* unstated policies on TSM investments).

In applying any of the evaluation techniques, therefore, a host of complex evaluation realities must be reckoned with. Meticulous technical analysis, based on sound data, and coolly reasoned professional judgement are required for a proper view on the relative cost-effectiveness of competing alternative freeway management system investments.

18.2 Measures of Effectiveness for Specific Goals and Objectives

Freeway management systems are always conceived with the expectation that substantial benefits will accrue to passenger and freight vehicles travelling within and through the limits of the project. Each system is designed to accomplish very specific goals and objectives (see Chapter 2: Exhibits 2b & 2f). In order to evaluate the degree of success of a freeway management system in achieving the chosen priority goals and objectives, and in order to identify possible enhancements to the adopted strategies and techniques, specific measures of effectiveness (MOEs) must be developed.

The selected MOEs may be used separately, or in combination, depending upon the application — however, they should be defined in such a manner that quantitative estimates of the daily operation of the system can be developed. Three sets of possible measures of effectiveness are presented in this section:

- MOEs for specific goals and objectives (Exhibit 18b)
- corridor throughput MOEs (Exhibit 18c)
- travel time MOEs (Exhibit 18d)

The measures of effectiveness should be specified in sufficient detail (ie. in terms of units), so that the data collection and analysis efforts can be designed to consider the following factors:

— time of day, weekday, special holidays, seasons of the year
— various traffic conditions
— exact type of incident
— vehicle type and occupancy
— each main section and facility in the freeway corridor (mainline, service roads, parallel arterials)
— corridor screenlines
— each sub-area and total system

Collection of detailed data, that can *not* be utilized, should be avoided.

It should be noted that Exhibits 18c and 18d were originally developed for an anticipated evaluation program for a major freeway management system in a large metropolitan corridor (IMIS). All freeway management systems will not require as many or even the same MOEs. The exhibits are simply presented here in order to stress the importance of determining the specific end use of the data that will be collected. For each freeway management system, the final measures of effectiveness will be different depending on the size of the system, on the importance placed on documenting its performance, and on the available resources to carry on with a data collection/analysis program over time.

Exhibit 18b

MEASURES OF EFFECTIVENESS FOR GOALS AND OBJECTIVES

GOALS	OBJECTIVES	MOE's
1. Improved vehicle thoughput	• Increase corridor throughput during peak periods • Accommodate new demand with existing facilities	• Volumes at selected screenlines • Vehicle-kilometres of travel (VKT)
2. Decreased and more predictable travel time	• Decrease average travel times • Reduce variability of average travel times • Reduce number of incidents	• Travel times (VHT) • Variance of VHT • Number of incidents per peak period
3. Rapid detection and removal of capacity reducing incidents	• Reduce incident detection time • Reduce incident response time • Reduce incident clearance time	• Incident detection time • Incident response time • Incident clearance time
4. Timely assistance to stranded motorists	• Reduce time between breakdown/stop and contact with authorities • Decrease response time to provide assistance	• Breakdown detection time • Breakdown assistance time
5. Reduction in accidents	• Reduce number of accidents • Reduce number of secondary accidents • Reduce severity of accidents	• Number of accidents • Number of secondary accidents • Number of fatal, personal injury and property damage accidents
6. Reduction in air pollution	• Reduce undesirable vehicle emissions	• Amount of carbon monoxide, hydrocarbons and nitrogen oxide (mg/m^3 in selected hot spots)
7. Reduction in energy consumption	• Reduce use of direct and indirect energy	• Litres of fuel consumed in construction & maintenance and by vehicles on the system • Tons of asphalt consumed
8. Reduction in vehicle operating costs	• Reduce fuel and maintenance costs	• Dollar cost of vehicle fuel & maintenance
9. Improved trip information	• Increase number of motorists given advisory information • Reduce number of lost motorists • Reduce accidents due to motorists confusion about direction or path • Increase accuracy and timeliness of advisory information	• Number of motorists given advisory information • Number of motorists seeking directions on CB radio & making last minute lane changes before exit ramps • Number of accidents • Accuracy & timeliness of information
10. Improved comfort of motorists	• Increase the ease of handling vehicle in traffic flow	• Motorists' perceptions
11. Improved management of existing highway facilities	• Increase effectiveness of road system (eg. utilization of all parallel facilities) • Defer/avert the cost of constructing and maintaining new facil's	• Extent of volume balancing amongst corridor facilities (across a screenline) • Number of years a major facility is deferred & accumulated interest on what would have been capital cost (of deferred facility)
12. Reduction of total number of vehicles in peak traffic flow	• Encourge solo drivers to shift into car, van and bus pools and to use regular public transit	• Number of new 2, 3 or 4+ person car pools • Number of new transit riders • Share of express bus runs (out of total)
13. Increased knowledge and experience with freeway managament	• Provide transferable results for use in planning and designing new projects throughout Canada	

Note: Table modified from FHWA report "IMIS Evaluation Plan."

Exhibit 18c

CORRIDOR THROUGHPUT MEASURES OF EFFECTIVENESS
—Examples of Tables and Figures—

TABLE or FIGURE	PURPOSE
Change in volume for non-incident conditions	
• at screenlines by time-of-day (tod)	• determine change in total corridor capacity
• for freeway vs. arterial links at screenlines by time-of-day	• determine volume shifts between facility types
• for bottleneck links saturated during peak periods (prior to installation)	• determine increase in capacity for critical links
• for selected roadway links (case by case)	• identify specific localized impacts
• for on-ramp/arterial pairs	• determine diversion to/from ramps in relation to ramp delay
Change in volume by incident	
• on upstream/downstream freeway links	• determine if throughput during incidents increased
• on upstream off-ramps, parallel arterials and connecting links	• determine extent to which diversion takes place by incident (type/duration)
Change in volume for average conditions	
• at cutlines by time-of-day	• determine change in overall corridor throughput
• for freeway vs. arterial links at cutlines by time-of-day	• determine volume shifts between facility types
Change in vehicle kilometres of travel (VKT) for average, non-incident and incident conditions	
• on total system by time-of-day	• determine basis for matching days of observation on the basis of travel
• for freeway vs. arterial links by time-of-day	• determine travel shifts amongst facility types
• for selected subareas by time-of-day	• determine localized shifts in travel patterns
Change in peak period vehicle occupancy	
• average vehicle occupancy for peak conditions by screenline	• determine person-kilometres of travel (PKT)
• specific vehicle occupancy by screenline (also: by time-to-day)	• determine number and percentage of vehicles with one, two, three and four+ persons
Change in peak period person kilometres of travel	
• for total system during average conditions	• determine change in total (system wide) person-kilometres of travel
• for freeway vs. arterial links at cutlines (also: by time-of-day)	• determine shifts in person travel by facility type
Vehicle classification by time period	
• totals across screenlines and for selected links	• establish distribution of vehicle types

Note: Exhibit modified from JHK & Associates/Dunn Engineering, P.C. proposal on IMIS evaluation submitted to FHWA/U.S. DOT.

Exhibit 18d

TRAVEL TIME MEASURES OF EFFECTIVENESS
—Examples of Tables and Figures—

TABLE or FIGURE	PURPOSE
Before and after mean speed profiles for average, non-incident and incident conditions	
• by time period for selected sets of parallel freeway and arterial road-ways — from moving car *or* detector data	• graphically show changes in speed profiles: freeway plots emphasize effectiveness of ramp-metering, arterial plots emphasize effectiveness of signal system
Before and after mean detector occupancy for average non-incident conditions	
• by time period for freeway links	• provide a measure of density or congestion
Percent of time detector occupancy exceeds threshold for average, non-incident and incident conditions	
• by time period for freeway links	• provide indication of percentage of time that certain freeway links are congested
Change in travel time for average, non-incident and incident conditions	
• by time period over freeway routes (use in conjunction with ramp delay table) — from moving car data — as estimated from system data	• determine change in travel time attributable to ramp metering
• by time period over arterial routes	• determine change in travel time attributable to signal system
Change in vehicle hours of travel (VHT) for average, non-incident and incident conditions	
• on total system by time-of-day	• overall measure of change in travel time
• on freeway vs. arterial links by time-of-day	• determine differences in changes by facility type
• by subarea by time-of-day	• determine localized changes in travel times
Change in coefficient of variation of VHT for average and non-incident conditions	
• on total system by time-of-day	• determine change in overall variability of travel time
• on freeway vs. arterial links by time-of-day	• determine variability in travel time by facility type
• by subarea by time-of-day	• determine variability in travel time by subarea

TRAVEL TIME MEASURES OF EFFECTIVENESS

—Examples of Tables and Figures—

TABLE or FIGURE	PURPOSE
Change in coefficient of variation of travel time for average, non-incident and incident conditions	
• by time period over selected routes	• determine change in variablity of travel time on selected routes
Ramp delay for average, non-incident and incident conditions	
• at selected metered ramps during peak and peak shoulder periods	• establish total freeway travel time and changes in travel time by subarea
Change in VKT/VHT ratio for average, non-incident and incident conditions	
• on total system by time-of-day	• composite measure of total system speed
• on freeway vs. arterial links by time-of-day	• determine overall change in speed by facility type
• by subarea by time-of-day	• determine overall change in speed by subarea
Change in number of stops on system-controlled arterial streets	
• by total arterial system by time-of-day	• determine effect of art. control strategies on stops

Note: Exhibit modified from JHK & Associates/Dunn Engineering, P.C. proposal on IMIS Evaluation submitted to FHWA/U.S. Dot.

18.3 Before/After Evaluation Studies

During the feasibility study phase, alternative freeway management systems and techniques are compared in order to identify the best alternative — which is then presented to the decision makers as 'recommended for implementation'. This recommendation is, by necessity, based on the estimated costs of the alternatives and on the benefits expected to result from the implementation of each. However analytically eloquent, the analysis must still be considered somewhat theoretical.

The major purpose of developing an *evaluation plan* is to determine the degree of *actual* improvement that can be realized from the techniques implemented. The degree of improvement can be expressed as a particular standard of achievement for:

a) average conditions;
b) incident conditions; and
c) non-incident or normal conditions.

The data collection efforts must be designed early in the process — preferably during the feasibility phase — to secure uncontaminated "before" data. The data must be for *current* freeway conditions — unencumbered by any installation activity (or other, unrelated maintenance, construction or transit strike activity), and unimproved by any management technique that may have been installed in advance of the full project. Then, after the project has been operating for sufficient length of time, data is collected to represent the "after" conditions. By comparing the before and the after data, conclusions can be made about the degree of improvement that has been actually realized by the implementation of the freeway management system.

For larger scale freeway management systems, the data collection and evaluation efforts can be designed to consist of the following four separate phases:

Long-Term Before Data — A long-term data collection effort could begin approximately two years to eight months before the completion of the freeway management system. The timing should be such that the possible effects in the freeway corridor (on its mainline, service roads, interchanges & intersections, alternative routes) — resulting from:

- installation and construction activities associated with the freeway management system;
- any other road maintenance, rehabilitation or construction activity
- major changes in transit service frequency or routes
- special events (eg. expo, olympics, etc) —

would be eliminated. (however, data should be also collected during these interruptions: in order to improve sketch planning capability for developing freeway management strategies for special situations and events).

Short-Term Before Data — For a freeway management system that includes electronic surveillance, an intensified data collection effort should begin after the surveillance system is installed and operational but before the control aspects are fully operational. The electronic surveillance system, instead of field personnel, should be used to collect volume and other data.

Short-Term After Data — Another short-term data collection effort should begin after the freeway management system has been found to be operating successfully and drivers have had the chance to adapt to the system. This intensive data collection effort is aimed at capturing the performance of the system before seasonal, traffic growth, or other long-term effects influence the travel patterns.

Long-Term After Data — The long term data collection effort should begin immediately after the completion of the short-term after data collection. It is designed to generate additional data for the relatively infrequent occurrences, such as severe accidents and fires.

After the collection, the before and after data are usually merged onto the same tables and figures. The change in each MOE (Exhibits 18b & 18c & 18d) is calculated and prominently displayed. For some of the MOEs, the results can also be presented by the following two methods:

- Level of Confidence — can be used to express the before/after improvement achieved. For instance, it may be concluded that it is 95% confident that the number of accidents has been reduced.

- Comparison of Before and After Conditions — can be expressed as the difference, or change, between the before and after conditions that has been achieved at a certain percent confidence level. For instance, it is 95% confident that the number of accidents has decreased by 20%.

Many freeway management operations are set up so, that the performance of the individual techniques as well as the overall system is continually monitored and evaluated. Information available from these projects can be utilized by the transportation planners and traffic engineers for demonstrating to the senior management the substantial benefits achievable by the relatively low cost (compared to the construction of new road or transit facilities) of freeway management systems.

Indeed, the basic characteristics of a metropolitan freeway corridor — ie.
— heavy traffic volumes
— recurring congestion
— numerous incidents
— maintenance activities
— construction activities —
contribute heavily to the occurrence of motorist delays, excess fuel consumption, emission of pollutants, occurrence of (additional) accidents, and extreme driver frustration. By employing measures of effectiveness to review the performance of a freeway management system operation, the success of the day-today management approach can be demonstrated and further enhancements identified. An examination of the evaluation data for existing projects in Canada and the United States will lead to the recognition that freeway management systems can be successfully implemented to achieve the ultimate goal of increasing the efficiency of passenger and freight transportation in major Canadian urban corridors.